9 • 12 • 2022

ЕЛЕКТРОТЕХНИКА И ЕЛЕКТРОНИКА

ELECTROTECHNICA & ELECTRONICA

E+E

PUBLISHED BY
CEEC – THE BULGARIAN UNION OF ELECTRONICS,
ELECTRICAL ENGINEERING AND TELECOMMUNICATIONS

JOURNAL E+E, 108 RAKOVSKI ST, 1000 SOFIA, BULGARIA, EPLUSE@CEEC.BG, WEB: EPLUSE.CEEC.BG

ELECTROTECHNICA & ELECTRONICA E+E

Vol. 57. No 9-12/2022

Monthly scientific and technical journal

Published by:
The Union of Electronics, Electrical Engineering and Telecommunications /CEEC/, BULGARIA

Technical editor: Zahari Zarkov

Corresponding address:
108 Rakovski St.
Sofia 1000
BULGARIA
Tel. +359 2 987 97 67
e-mail: epluse@ceec.bg
http://epluse.ceec.bg

ISSN 0861-4717 Print
eISSN 2603-5421 Online

C O N T E N T S

Energy efficiency improvements in electric drives with centrifugal load

Mihail Digalovski, Goran Rafajlovski, Krste Najdenkoski

Electric drives with centrifugal torque characteristic are a typical low efficiency drives. These include fans, pumps, blowers etc. In these electric drives, there is great technical and economic potential for significant energy savings. Pumps are the most numerous working machines, therefore the electric drives with pump will be considered in this paper. First, as opportunity to increase energy efficiency will be presented the replacement of existing electric motors in these drives with highly efficient motors - HEM. Will be made an analysis how much is savings due to reduced losses in highly efficient electric motors. The next, will be given a brief introduction to pump systems and then will be presented the ways in which the operating point of the pump can be regulated. In addition, is presented a calculation for energy savings was made a comparison between conventional ways of regulating the operating point of the pump and regulation of the operating point through variable electric drive speed. It analyzes the electricity consumption of low, medium and high-power pumps driven by induction motors that have the ability to regulate the rotation speed through an inverter with U/f regulation.

Keywords – Energy Efficiency, Pump Electric Drives, Centrifugal Mechanical Characteristic, High Efficient Electric Motors - HEM, U/f regulation.

1. Introduction

Energy efficiency is the taking of various measures to improve the operation and quality of a particular process and to reduce electricity consumption, and thus to reduce the negative impact on the environment. Thereby, the increased energy efficiency of a certain electric drives must not be at the account of the reduction of production and profitability. In Europe from 2003 to 2012 lasted the Motor Challenge Program - a program supported and supported by the European Commission that aimed to help industrial companies improve the energy efficiency of their electric drives to improve the production process in industry by increasing the quantity and quality and reduce their impact on the environment, especially with the emission of greenhouse gases into the air [1]. The program puts its emphasis on the drives with working mechanisms that are most common, such as the drives with pumps in the first place which are represented with 33% of all working mechanisms, then compressors, fans, blowers, etc., where there is great technical and economic potential for significant energy savings. The program focused on efforts for application of increased efficiency mechanisms that have the greatest share in improving drive efficiency, followed by the application of energy converters and finally the use of high efficient motors - HEM.

Highly efficient drives can reduce the cost of maintaining them, improve drive performance, increase productivity and profitability, reduce system losses and thus reduce electricity consumption. If this were to be realized globally, it would result in less need for generation capacity, lower losses in electricity transmission and a cleaner environment. Inefficient use of electricity increases in proportion to the increase in electricity consumption, increased activity in the economy and the use of outdated technology.

In this paper highlights the importance of energy efficiency in electric drives and what it represents. At electric drives, there are two possible ways to increase energy efficiency. One of them is the application of highly efficient induction motors [1]. It shows the energy efficiency classes according to a standard published by the International Commission for Electrical Engineering and presents the electricity consumption for all standard powers up to 1MW in induction motors (IM) operating at nominal load 2000, 4000 and 6000 hours per year, respectively according to the energy class to which they belong. In addition, a comparison is made when replacing a standard efficiency motor with a motor with the highest efficiency class to see what the impact of high efficient motors is on improving energy efficiency and energy savings. The second way that is considered and

contributes to the improvement of energy efficiency at electric drives involves the application of energy converters. For this purpose, scalar U/f regulation is explained as one of the ways to regulate it. Then an example is presented for improving the energy efficiency of the electric drives with pumps in which the regulation of the operating point is needed. To be clear, a brief introduction to pumping systems and their characteristics is given. Furthermore, is calculates energy savings in operating point regulation by applying inverters with U/f regulation compared to operating point regulation with mechanical control. An analysis was made of seventeen types of centrifugal pumps with low, medium and high power driven by induction motors. At the end, the results are presented, conclusions are drawn and the benefits of the implementation of energy converters are listed.

2. Realization of energy efficiency in electric drives

The efficiency of an electric drives is determined by the components that assembled that drive, i.e. it is a product of the efficiencies of the individual components that assembled the system. These include first of all the efficiency of the working mechanism, then the efficiency of the control system, the efficiency of the electric motor, the efficiency of the mechanical transmission system if it exists, etc. High efficient motors and energy converters regulation will be presented below.

2.1. Use of high efficient motors (HEM)

In March 2014, the standard IEC 60034-30-1: 2014 was published by the International Commission for Electrical Engineering (IEC), which includes single-phase and three-phase induction cage motors [2]. This standard replaces and extends IEC 60034-30: 2008 which defined three energy efficiency classes for induction cage motors. The new standard from 2014 includes four classes of energy efficiency, includes induction cage motors up to 8 poles, nominal voltage of 50 - 1000 V and output power of 0.12 - 1000 kW.

The following energy efficiency classes are included in IEC 60034-30-1:

- IE1 (Standard Efficiency)
- IE2 (High Efficiency)
- IE3 (Premium Efficiency)
- IE4 (Super Premium Efficiency)

Application field of the standard:

- Power range: 0.12 - 1000 kW
- Voltage range: up to 1 kV
- Frequency: 50Hz / 60Hz
- Number of poles: 2,4,6,8
- Degree of protection: all
- Temperature range: -20ºC to + 40ºC
- Altitude: up to 4000 m
- Load character: S1

Although IEC standards are applied by many countries in the world, there are differences in their implementation. IEC 60034-30-1: 2014 defines and proposes only the requirements for energy efficiency classes to create a basis for international consistency. It does not specify which motors the energy class must have. This is a specified in national legislation.

The European Union cooperates with the International Electrotechnical Commission and applies many of the standards published by them. Since July, 2011 the European Commission, which is part of the European Union, adopts a regulation according to which induction motors with output power range from 7.5 to 375 kW should not be less efficient than the efficiency specified by the energy class IE2. Since January, 2015 all induction motors with output power range from 7.5 to 375 kW is adopted not to be with energy class lower than IE3 or IE2 if connected via a power converter, and from January 2017 the same applies as the power range increases, from 0.12 - 1000 kW [2].

The following graph shows all four classes of energy efficiency according to IEC 60034-30-1: 2014, i.e. shows the range in which the efficiency of the engine can move depending on the power, to belong to a certain class of efficiency.

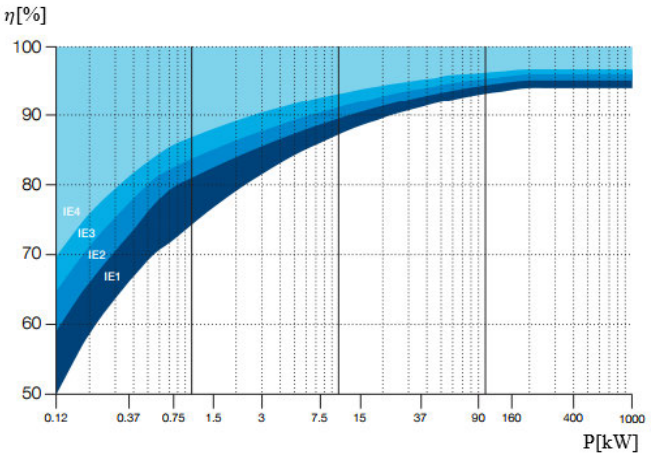


Fig. 1. Energy efficiency classes for four-pole IM, 50 Hz according to IEC 60034-30-1: 2014 [2].

Figure 2 presents a simple analysis of the distribution of costs required in the fifteen-year work life of a three-phase induction motor of the energy class IE2 with a nominal power of 11 kW for 2000, 4000 and 6000 operating hours per year.

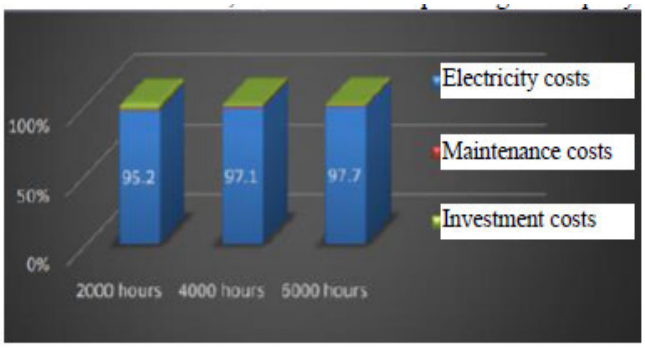


Fig. 2. Analysis of the required costs during 15 years work life for 11kW IM [3].

If induction motors run a large number of hours per year and have a long work life, the capital investment does not have the largest share in the total cost for the entire work life of the motor. As can be seen, the costs related to electricity consumption have the largest share. More than 95% of the total funds required during the 15-year motor life are allocated to the funds required for the consumed electricity. The result of the analysis confirms the fact that even a marginal increase in motor efficiency is crucial to reduce electricity costs, which in turn contributes to reducing its impact on the environment.

In addition, the corresponding minimum values for energy efficiency will be presented in a table, which according to IEC 60034-30-1: 2014 should satisfy the three-phase induction cage motors with 2, 4, 6 and 8 poles to belong to the corresponding energy class depending on rated power. Table 1 presents the energy efficiencies η [%] for energy classes IE1, IE2, IE3 and IE4 for induction motors with 2 and 4 poles, and Table 2 for 6 and 8 poles.

Depending on the purpose and the drive, the motors can have different number of working hours per year. Table 3 shows the price in euros for electricity consumed in one year if a 2-pole motor operates with a nominal load of 2000, 4000 and 6000 hours per year. The price of electricity is assumed to be 0.12 euros per kWh. The calculations are made for motors with nominal power from 11kW to 1000kW.

$$E = \frac{P[kW] \cdot t[h] \cdot \text{electricity price}[€ \text{ per kWh}]}{\eta} \qquad (1)$$

t - number of working hours per year; η - motor energy efficiency

It can be concluded that with the increase of the energy efficiency, i.e. with the increase of the energy efficiency class of IM, the consumed electricity decreases. In addition, it will be presented how much is the improvement of motor efficiency in percent, and what are the savings in money for the saved electricity depending on the power and the number of working hours per year if a motor with 2 poles of energy class IE1 is replaced with the same such as energy class IE4, and the price for electricity is 0.12 € per kWh.

As can be seen from Table 4, replacing an induction motor of a lower energy class with an induction motor of a higher energy class may increase the efficiency k of the system from 2.5% to 5%. The savings are most pronounced in motors that have more working hours per year and more power. It is clear that more efficient engines with a higher energy efficiency class are more expensive compared to those with lower energy efficiency, but at the same time bring greater energy savings and have a shorter time to return on capital investment.

Table 1. Energy efficiency classes at IM with 2 and 4 poles according to IEC 60034-30-1: 2014.

P			2 poles			4 poles		
kW	IE1	IE2	IE3	IE4	IE1	IE2	IE3	IE4
0.12	45.0	53.6	60.8	66.5	50.0	59.1	64.8	69.8
0.18	52.8	60.4	65.9	70.8	57.0	64.7	69.9	74.7
0.20	54.6	61.9	67.2	71.9	58.5	65.9	71.1	75.8
0.25	58.2	64.8	69.7	74.3	61.5	68.5	73.5	77.9
0.37	63.9	69.5	73.8	78.1	66.0	72.7	77.3	81.1
0.40	64.9	70.4	74.6	78.9	66.8	73.5	78.0	81.7
0.55	69.0	74.1	77.8	81.5	70.0	77.1	80.8	83.9
0.75	72.1	77.4	80.7	83.5	72.1	79.6	82.5	85.7
1.10	75.0	79.6	82.7	85.2	75.0	81.4	84.1	87.2
1.50	77.2	81.3	84.2	86.5	77.2	82.8	85.3	88.2
2.20	79.7	83.2	85.9	88.0	79.7	84.3	86.7	89.5
3.00	81.5	84.6	87.1	89.1	81.5	85.5	87.7	90.4
4.00	83.1	85.8	88.1	90.0	83.1	86.6	88.6	91.1
5.50	84.7	87.0	89.2	90.9	84.7	87.7	89.6	91.9
7.50	86.0	88.1	90.1	91.7	86.0	88.7	90.4	92.6
11	87.6	89.4	91.2	92.6	87.6	89.8	91.4	93.3
15	88.7	90.3	91.9	93.3	88.7	90.6	92.1	93.9
18.50	89.3	90.9	92.3	93.7	89.3	91.2	92.6	94.2
22	89.9	91.3	92.7	94.0	89.9	91.6	93.0	94.5
30	90.7	92.0	93.3	94.5	90.7	92.3	93.6	94.9
37	91.2	92.5	93.7	94.8	91.2	92.7	93.9	95.2
45	91.7	92.9	94.0	95.0	91.7	93.1	94.2	95.4
55	92.1	93.2	94.3	95.3	92.1	93.5	94.6	95.7
75	92.7	93.8	94.7	95.6	92.7	94.0	95.0	96.0
90	93.0	94.1	95.0	95.8	93.0	94.2	95.2	96.1
110	93.3	94.3	95.2	96.0	93.3	94.5	95.4	96.3
132	93.5	94.6	95.4	96.2	93.5	94.7	95.6	96.4
160	93.8	94.8	95.6	96.3	93.8	94.9	95.8	96.6
200	94.0	95.0	95.8	96.5	94.0	95.1	96.0	96.7
250	94.0	95.0	95.8	96.5	94.0	95.1	96.0	96.7
315	94.0	95.0	95.8	96.5	94.0	95.1	96.0	96.7
355	94.0	95.0	95.8	96.5	94.0	95.1	96.0	96.7
400	94.0	95.0	95.8	96.5	94.0	95.1	96.0	96.7
450	94.0	95.0	95.8	96.5	94.0	95.1	96.0	96.7
1000	94.0	95.0	95.8	96.5	94.0	95.1	96.0	96.7

Table 2. Energy efficiency classes at IM with 6 and 8 poles according to IEC 60034-30-1: 2014.

P	6 poles				8 poles			
kW	IE1	IE2	IE3	IE4	IE1	IE2	IE3	IE4
0.12	38.3	50.6	57.7	64.9	31.0	39.8	50.7	62.3
0.18	45.5	56.6	63.9	70.1	38.0	45.9	58.7	67.2
0.20	47.6	58.2	65.4	71.4	39.7	47.4	60.6	68.4
0.25	52.1	61.6	68.6	74.1	43.4	50.6	64.1	70.8
0.37	59.7	67.6	73.5	78.0	49.7	56.1	69.3	74.3
0.40	61.1	68.8	74.4	78.7	50.9	57.2	70.1	74.9
0.55	65.8	73.1	77.2	80.9	56.1	61.7	73.0	77.0
0.75	70.0	75.9	78.9	82.7	61.2	66.2	75.0	78.4
1.10	72.9	78.1	81.0	84.5	66.5	70.8	77.7	80.8
1.50	75.2	79.8	82.5	85.9	70.2	74.1	79.7	82.6
2.20	77.7	81.8	84.3	87.4	74.2	77.6	81.9	84.5
3.00	79.7	83.3	85.6	88.6	77.0	80.0	83.5	85.9
4.00	81.4	84.6	86.8	89.5	79.2	81.9	84.8	87.1
5.50	93.1	86.0	88.0	90.5	81.4	83.8	85.2	88.3
7.50	84.7	87.2	89.1	91.3	83.1	85.3	87.3	89.3
11	86.4	88.7	90.3	92.3	85.0	86.9	88.6	90.4
15	87.7	89.7	91.2	92.9	86.2	88.0	89.6	91.2
18.50	88.6	90.4	91.7	93.4	86.9	88.6	90.1	91.7
22	89.2	90.9	92.2	93.7	87.4	89.1	90.6	92.1
30	90.2	91.7	92.9	94.2	88.3	89.8	91.3	92.7
37	90.8	92.2	93.3	94.5	88.8	90.3	91.8	93.1
45	91.4	92.7	93.7	94.8	89.2	90.7	92.2	93.4
55	91.9	93.1	94.1	95.1	89.7	91.0	92.5	93.7
75	92.6	93.7	94.6	95.4	90.3	91.6	93.11	94.2
90	92.9	94.0	94.9	95.6	90.7	91.9	93.4	94.4
110	93.3	94.3	95.1	95.8	91.1	92.3	93.7	94.7
132	93.5	94.6	95.4	96.0	91.5	92.6	94.0	94.9
160	93.8	94.8	95.6	96.2	91.9	93.0	94.3	95.1
200	94.0	95.0	95.8	96.3	92.5	93.5	94.6	95.4
250	94.0	95.0	95.8	96.5	92.5	93.5	94.6	95.4
315	94.0	95.0	95.8	96.6	92.5	93.5	94.6	95.4
355	94.0	95.0	95.8	96.6	92.5	93.5	94.6	95.4
400	94.0	95.0	95.8	96.6	92.5	93.5	94.6	95.4
450	94.0	95.0	95.8	96.6	92.5	93.5	94.6	95.4
1000	94.0	95.0	95.8	96.6	92.5	93.5	94.6	95.4

Table 3. Costs for electricity consumed in euros per year depending on the energy class and the number of working hours per year for induction motors with 2 poles.

P	2000 h				4000 h				6000 h			
kW	IE1	IE2	IE3	IE4	IE1	IE2	IE3	IE4	IE1	IE2	IE3	IE4
11	3013.7	2953	2894.7	2851	6027.4	5906	5789.5	5701.9	9041.1	8859.1	8684.2	8552.9
15	4058.6	3986.7	3917.3	3858.5	8117.2	7973.4	7834.6	7717	12175.9	11960.1	11751.9	11575.6
18.50	4972	4884.5	4810.4	4738.5	9944	9769	9620.8	9477.1	14916	14553.5	14431.2	14215.6
22	5873.2	5783.1	5695.8	5617	11746.4	11566.3	11391.6	11234	17619.6	17349.4	17087.4	16851.1
30	7938.3	7826.1	7717	7619	15876.5	15652.2	15434.1	15238.1	23814.8	23478.3	23151.1	22857.1
37	9736.8	9600	9477.1	9367.1	19473.7	19200	18954.1	18734.2	29210.5	28800	28431.2	28101.3
45	11777.5	11625.4	11489.4	11368.4	23555.1	23250.8	22978.7	22736.8	35332.6	34876.2	34468.1	34105.3
55	14332.2	14163.1	13997.9	13851	28664.5	28326.2	27995.8	27702	42996.7	42489.3	41993.6	41553
75	19417.5	19189.8	19007.4	18828.5	38835	38379.5	38014.8	37656.9	58252.4	57569.3	57022.2	56485.4
90	23225.8	22954.3	22736.8	22547	46451.6	45908.6	45473.7	45093.9	69677.4	68862.9	68210.5	67640.9
110	28295.8	27995.8	27731.1	27500	56591.6	55991.5	55462.2	55000	84887.5	83987.3	83193.3	82500
132	33882.4	33488.4	33207.5	32931.4	67764.7	66976.7	66415.1	65862.8	101647	100465	99622.6	98794.2
160	40938.2	40506.3	40167.4	39875.4	81876.3	81012.2	80334.7	79750.8	122815	121519	120502	119626
200	51063.8	50526.3	50104.4	49740.9	102123	101053	100209	99481.9	153192	151579	150313	149223
250	63829.8	63157.9	62630.5	62176.2	127660	126316	125261	124352	191489	189474	187891	186529
315	80425.5	79578.9	78914.4	78342	160851	159158	157829	156684	241277	238737	236743	235026
355	90638.3	89684.2	88935.3	88290.2	181277	179368	177871	176580	271915	269053	266806	264871
400	102128	101053	100209	99481.9	204255	202105	200418	198964	306383	303158	300626	298446
450	114894	113684	112735	111917	229787	227368	225470	223834	344681	341053	338205	335751
1000	255319	252632	250522	248705	510633	505263	501044	497409	765957	757895	751566	746114

Table 4. Money savings in Euros when replacing IM of energy class IE1 with IM of energy class IE4 depending on the number of working hours per year.

P [kW]	k [%]	2000 h	4000 h	6000 h
11	5	162.7	325.5	488.2
15	4.6	200.1	400.2	600.3
18.50	4.4	233.5	466.9	700.4
22	4.1	256.2	512.4	768.5
30	3.8	319.3	638.4	957.7
37	3.6	369.7	739.5	1109.2
45	3.3	409.1	818.3	1227.3
55	3.2	481.2	962.5	1443.7
75	2.9	589	1178.1	1767
90	2.8	678.8	1357.7	2036.5
110	2.7	795.8	1591.6	2387.5
132	2.7	951	1901.9	2852.9
160	2.5	1062.8	2125.5	3188.3
200	2.5	1322.9	2645.8	3968.7
250	2.5	1653.6	3307.3	4960.9
315	2.5	2083.5	4167.2	6250.7
355	2.5	2348.1	4696.3	7044.4
400	2.5	2645.8	5291.6	7937.4
450	2.5	2976.5	5953	8929.6
1000	2.5	6614.4	13229	19843.4

2.2. Use of U/f electric motor regulation v.s. valve regulation in a pump system

Fig. 3 shows a diagram for the regulation of water flow through a pump in two ways. The aim is to change the water flow from Q_1 to Q_2. The first is the conventional way, with mechanical control, i.e. with the use of a control valve where the motor speed does not change. The second way is by regulating the motor speed through an inverter.

- **Valve control**

To reduce the flow from Q_1 to Q_2 it is necessary to close properly the regulating valve. The operating point of the pump is moved along the characteristic H=f(Q) marked in Fig. 1 as P_1, and passes from the system characteristic S_1 to the system characteristic S_2. The system characteristic changes from S_1 to S_2 because resistance is added to the system (damping) i.e. the hydraulic losses increase. Increasing the hydraulic losses by closing the valve, increases the effort that the pump has to make to overcome those losses during flow Q_2. In fact, damping changes the coefficient of resistance of the pipeline and thus changes the position of the operating point of the pump along the curve P_1=H=f(Q). The pump effort increases from H_1 to H_{2S}.

- **Motor speed control**

To reduce the flow from Q_1 to Q_2, the operating point of the pump is shifted from characteristic P_1 with a rotational speed n_1 of the P_2 curve with a reduced engine speed n_2. By reducing the motor speed at flow Q_2, the effort required for the pump to overcome system losses and the required pressure is reduced from H_1 to H_{2P}.

Significant energy savings can only be achieved if a wider range of control is required. If the process does not require any regulation and is constant and not dynamic then there can be no question of saving energy by changing the working point. However, a small percentage of processes do not need regulation.

In many activities related to human life such as water supply systems, heating, air conditioning, condensate cooling in industrial processes, etc. due to different activities and needs during different parts of the day, different seasons, different processes, etc. regulated processes are necessary.

2.2.1 Result analysis

The purpose of the analysis is to compare the two ways of regulation of flow in an arbitrarily selected pump and to show the saved electricity if the flow is regulated by changing the speed of rotation compared to the conventional way of regulation by using regulating valves. The equations used for the analysis are given below:

Required mechanical power of the pump shaft in both regimes of regulation is:

Required pump power for valve control, P_v:

$$P_V = \frac{Q_m[m^3/h] \cdot H_{2S}[m] \cdot \rho[kg/dm^3] \cdot g[m/s^2]}{3600 \cdot \eta_1} [kW] \quad (2)$$

Required pump power for motor speed control, P_e:

$$P_e = \frac{Q_m[m^3/h] \cdot H_{2P}[m] \cdot \rho[kg/dm^3] \cdot g[m/s^2]}{3600 \cdot \eta_2} [kW] \quad (3)$$

Required electrical power in both regimes of regulation is:

Required electrical power for valve control, P_{1m}:

$$P_{1m} = \frac{P_V}{\eta_m} [kW] \quad (4)$$

Required electrical power for motor speed control, P_{2m}:

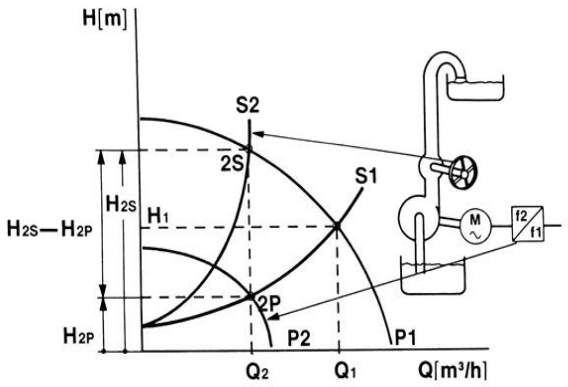
$$P_{2m} = \frac{P_e}{\eta_m \cdot \eta_{vfd}} [kW] \quad (5)$$

Energy saving, E_s:

$$E_s = (P_{1m} - P_{2m}) \cdot t_a [kWh/year] \quad (6)$$

Saving money per year, K_s:

$$K_s [savig\ many\ per\ year] = E_S [kWh/year] \cdot k [price/kWh] \quad (7)$$



P_1 - pump characteristic at rated speed n_1 [min^{-1}]
P_2 - pump characteristic at reduced speed n_2 [min^{-1}]
S_1 - system characteristic
S_2 - system characteristic
Q_1, Q_2 - pump flow [m^3/h]
H_{2S} - pump effort expressed in [m] at flow Q_2 during valve control
H_{2P} – pump effort expressed in [m] at flow Q_2 during motor speed control

Fig. 3. Centrifugal pump flow regulation [4].

Where is: ρ [kg/dm^3] – liquid density; g [m/s^2] - ground acceleration; η_1 - pump efficiency at operating point 2S, Fig. 3; η_2 - pump efficiency at operating point 2P, Fig. 3; η_m - motor efficiency; η_{vfd} - efficiency of the inverter; t_a - number of working hours per year.

In order to evaluate the efficiency of the two solutions that can regulate the water flow through the pump, it is necessary to make an analysis for a specific pump. For this purpose, a comparison and analysis of the two regulation modes on 17 types of centrifugal single-stage pumps was made, selected from the catalogue of the pump manufacturer Grundfos [5]. The pumps are from the same family and are powered by high efficient induction motors with low, medium and high power. The power range of the motors that will be considered is from 1.5kW to 426kW.

The parameters used in the calculations are taken from the characteristics of each of the pumps from the appropriate catalogues. Table 5 provides data on the pumps used in the analysis, such as the type and serial number of the pump, the rated power of the pump and the induction motor in the drive, nominal flow and effort, efficiency, efficiency class and number of poles.

Table 6 shows the data for the operating point of each of the pumps and the corresponding efficiencies depending on it in both regulation modes, then shows the efficiency of the motor that drives each of the pumps, the number of working hours per year and the price per consumed kWh electric energy. The analysis goes in the direction of changing the operating point of the pump. A flow reduction of 20% of the nominal was made.

Table 5. Pumps data [5].

Pump serial number	P_n [kW]	P_2 [HP]	Q_n [m^3/h]	H_n [m]	η_{pn} [%]	η_{mn} [%]	IE	poles
NKE 32-125.1/121 A1-F-A-E-BAQE	1.5	2	19.7	15.7	63.0	88.9	IE4	2
NKE 32-125.1/140 A1-F-A-E-BAQE	2.2	3	23.4	22.6	67.4	90.1	IE4	2
NKE 32-160/151 A2-F-L-E-BQQE	3	4	24.8	24.9	61.1	87.1	IE3	2
NKE 32-160/177 A2-F-K-E-BQQE	5.5	7.5	32.5	36.1	65.4	89.2	IE3	2
NKE 40-160/172 A1-F-A-E-BAQE	7.5	10	43.7	38.6	75.3	90.1	IE3	2
NKE 40-160/177 A2-F-A-E-BAQE	11	15	46.0	41.5	75.3	89.4	IE2	2
NKE 40-200/219 A2-F-L-E-BQQE	15	20	60.2	51.9	69.3	90.3	IE2	2
NKGE 150-125-250/249 A1-F-A-E-BAQE	18.5	25	254	17.4	79.8	91.2	IE2	4
NB 65-250/238 AS-F2-B-E-BAQE	37	50	134	68.1	72.7	92.6	IE2	2
NB 65-250/251 A-F2-A-E-BAQE	45	60	145	77.0	73.6	93.7	IE3	2
NB 65-250/270 AS-F-B-E-BAQE	75	100	161	89.5	75.0	94.6	IE3	2
NK 80-315/295 A1-F-A-E-BAQE	110	150	244	113.8	75.5	94.3	IE2	2
NKG 125-80-315/310 A1-F-L-E-BQQE	132	180	263	126.8	75.5	94.6	IE2	2
NK 80-315/328 A1-F-I-E-BQQE	160	210	289	143.7	76.8	95.6	IE3	2
NKG 125-80-400/398 A1-F-R-E-DAQF	250	340	289	196.9	70.2	95.4	IE2	2
NKG 200-150-315.1/335 G1-F-A-E-BAQE	355	480	965	148.9	83.0	95.5	IE2	2
TP 400-540/4 A-F-A-DBUE	450	540	2890	35.0	83.1	94.0	IE2	4

Table 6. Pumps working point data.

P [kW]	Qm [m3/h]	H2S [m]	H2P [m]	η1 [%]	η2 [%]	ηm [%]	ta [h]	[€/kWh]	Hmin [m]
1.5	15.8	17.37	8.702	60.4	62.8	88.9	3000	0.12	8
2.2	18.7	24.67	12.77	65.6	67.0	90.1	3000	0.12	12
3	18.4	27.6	14.43	57.8	61.1	87.1	3000	0.12	14
5.5	26	39.6	19.57	64.0	64.8	89.2	3000	0.12	19
7.5	35	41.46	21.83	71.0	75.0	90.1	3000	0.12	21
11	36.8	44.42	23.56	71.0	76.1	89.4	3000	0.12	23
15	48.2	58.4	29.24	68.4	69.1	90.3	3000	0.12	29
18.5	203	19.58	9.938	77.0	80.1	91.2	3000	0.12	9
37	107	75.1	38.22	71.0	72.6	92.6	3000	0.12	38
45	116	85	42.34	72.6	73.3	93.7	3000	0.12	42
75	130	98.66	48.78	74.2	74.4	94.6	3000	0.12	48
110	195	121.5	51.5	73.8	75.0	94.3	5000	0.12	61
132	210	134.8	71.03	73.3	75.4	94.6	5000	0.12	71
160	231	152.7	79.37	74.8	76.5	95.6	5000	0.12	79
250	231	213.7	107	69.1	70.1	95.4	5000	0.12	107
355	773	131.2	69.53	81.6	85.0	95.5	5000	0.12	69
450	2310	41.27	18.69	79.5	82.6	94.0	5000	0.12	18

When **regulating the valve opening**, to reduce the flow by 20% from $Q_1=Q_n$ to $Q_2 = Q_m$ (Fig. 3), it is necessary to close it properly. The operating point of the pump moves along the characteristic $P_1=H=f(Q)$ and passes from the system characteristic S_1 to the system characteristic S_2. The speed at which the motor runs is 100% of the nominal. The pump effort increases from H_1 to H_{2S}.

When regulating the motor speed to reduce the flow by 20% from Q_1 to $Q_2=Q_m$, the operating point of the pump is shifted from characteristic P_1 with a rotational speed n_1 of the P_2 curve with a reduced engine speed n_2. By reducing the rotational speed of the motor at flow Q_2, the effort required for the pump to overcome system losses and the required pressure is reduced from H_1 to H_{2P}. The percentage for which the rotation speed should be reduced in order to achieve the required flow depends on the characteristics of the system, i.e. the system characteristic. In other words, the percentage of speed reduction can't be arbitrary but depends on how much effort the pump has to withstand at reduced flow. For the purposes of this analysis the speed of all analyzed pumps is reduced by 25% of the nominal, which means the motor is running at 75% of the nominal speed and it is assumed that the total effort that the pump has to overcome is not greater than the value H_{min} of Table 6.

The pump data shown in Table 6, as previously stated, are the data required to perform the calculations, and an explanation of the variables is given below:

Q_m - flow through the pump [m^3/h]; H_{2S} - pump effort expressed in [m] at Q_m flow with valve regulation and rated motor speed; H_{2P} - pump effort expressed in [m] at Q_m flow with motor speed regulation with inverter at 75% of nominal speed; η_1 - pump efficiency at operating point (Q_m, H_{2S}); η_2 - pump efficiency at operating point (Q_m, H_{2P}); η_m - motor efficiency; t_a - number of working hours per year.

Table 7 shows the results of the calculation for each of the pumps defined in Table 5 and Table 6, where: P_v (kW) - required pump power for valve regulation; P_e (kW) - required pump power for motor speed regulation at 75% of rated speed; P_s (%) - percentage of power required less when the flow is regulated by motor speed to 75% of the nominal compared to the valve regulation ($P_s = (Pe/P_v) \times 100$); E_s (kWh) - saving electricity by applying an energy converter with U/f regulation at a reduced speed of 25%; K_s (€) - saving money from the saved electricity.

Table 7. Result analysis.

P [kW]	PV [kW]	Pe [kW]	PS [%]	ES [kWh]	KS [€]
1.5	1.238	0.597	48.183	2165.100	259.810
2.2	1.916	0.971	50.682	3146.900	377.620
3	2.394	1.184	49.459	4167.900	500.140
5.5	4.384	2.140	48.809	7547.500	905.700
7.5	5.569	2.776	49.845	9300.700	1116.100
11	6.274	3.105	49.845	10635.000	1276.200
15	11.214	5.558	49.561	18792.000	2255.000
18.5	14.066	6.863	48.792	23695.000	2843.400
37	30.841	15.350	49.771	50188.000	6022.600
45	37.009	18.259	49.336	60033.000	7203.900
75	47.103	23.226	49.310	75719.000	9086.200
110	87.482	43.573	49.807	232819.297	27983.315
132	105.237	53.908	51.225	271297.099	32555.651
160	128.503	65.309	50.822	330516.350	39661.962
250	194.672	96.082	49.355	516719.967	62006.396
355	338.680	172.305	50.875	871070.850	104528.502
450	326.773	142.432	43.588	980535.586	117664.270

As can be seen from the results of the table, the regulation of the motor speed by using energy converters as a way to change the operating point of the pump is a much more efficient solution compared to the valve control and brings great savings in electricity if it is the same implements. This is especially true for drives that have variable operating regimes.

3. Conclusion

The world industry and economy are facing a major energy challenge. Global electricity demand is growing, and pressures to reduce electricity consumption and reduce the impact on the environment and climate change are growing. If we take into account the fact that as much as 65% -70% of the total electricity consumption in industry is accounted for by electric motors then it is clear that the potential for saving electricity is huge and their role in reducing environmental pollution is crucial.

The biggest part in the improvement of the energy efficiency of an electric drives has the improvement of the efficiency of the working mechanism. In second place are the application of energy converters and then the use of high efficient motors - HEM. The application of energy converters and high efficient motors - HEM are profitable investments, whose return depending on the number of working hours and power, and is from several months to 5 years.

Replacing an standard energy efficiency induction motor (energy class IE1) with a high efficient motor (energy class IE4) can improve the system energy efficiency from 20% for low power motors to a few percent for high power motors. However, the improvement of energy efficiency even by 2% in high power IM contributes to large electricity savings.

To reduce the pump flow by only 20% at a reduced motor speed of 25% of the nominal, the power required by the pump is 50% lower than the power required for valve control. This is a significant reduction in power and a confirmation of the general law which states that the power of a pump depends on the cube of the speed at which it rotates. Reducing the flow of a pump with a valve control is just as inefficient as regulating the car speed only with brakes. Mechanical control consumes electricity unnecessarily. How much is higher the number of working hours and the higher the power of the pump, the energy savings is greater. Knowing that pumps make up 33% of all working mechanisms, it is concluded that by increasing the energy efficiency of pump systems there is a great potential for saving energy and improving their work.

The concept of energy efficiency is a very effective way to reduce the emission of carbon dioxide and other harmful substances into the air that contribute to global warming, air pollution and climate change. Global programs aimed at helping industrial companies improve the energy efficiency of their electric drives are needed and are of great importance for raising awareness and assisting in the implementation of energy efficiency.

This article is presented at the 36th International Conference on Information Technologies (InfoTech-2022), IEEE Conference, Rec. # 55606, September 15-16, 2022, Bulgaria.

REFERENCES

[1] E. Commission, "Motor Challenge Program," 2009.

[2] ABB, www.abb.com, Available: http://new.abb.com/.

[3] F. C. Systems, "Massive savings with industrial process energy saving solutions", Finesse Control Systems Ltd. Available: http://www.finessecs.com/industrial-energy-saving-solutions.html.

[4] ABB, "Variable speed control form demand to decision".

[5] GRUNDFOS, "Products", GRUNDFOS. Available: http://www.grundfos.com/products.html.

[6] GRUNDFOS, http://www.grundfos.com/, Available: http://net.grundfos.com/doc/webnet/mining/_downloads/pump-handbook.pdf.

Mihail Digalovski *was born in Skopje, Macedonia, on September 16, 1980. He recived Ph.D. degree in Electrical Engineering from "Ss. Cyril and Methodius University", Faculty of Electrical Engineering and Information Technologies, Skopje, Republic of North Macedonia in 2014. He is a member of IEEE Power Engineering Society and CIGRE Paris. His field of interest includes transformers, electrical machines and drives, electric power measurements and diagnostic, modern optimization methods. At the moment he is Associate Professor in the "Ss. Cyril and Methodius University", Faculty of Electrical Engineering and Information Technologies, Skopje, Republic of North Macedonia.*

e-mail: mihaild@feit.ukim.edu.mk

Goran Rafajlovski *was born in Skopje, Macedonia, on May 2, 1963. He recived Ph.D. degree in Electrical Engineering from "Ss. Cyril and Methodius University", Faculty of Electrical Engineering and Information Technologies, Skopje, Republic of North Macedonia in 1996. He is a member of DAAD Alumni, IEEE IAS Power Engineering Society and CIGRE Paris. His field of interest includes renewable, power quality, electrical machines and drives, power electronics and energy efficiency control techniques. He is today a Full Professor in the "Ss. Cyril and Methodius University", Faculty of Electrical Engineering and Information Technologies, Skopje, Republic of North Macedonia.*

e-mail: goran@feit.ukim.edu.mk

Krste Najdenkoski *was born in Ohrid, Macedonia, on November 11, 1965. He recived Ph.D. degree in Electrical Engineering from "Ss. Cyril and Methodius University", Faculty of Electrical Engineering and Information Technologies, Skopje, Republic of North Macedonia in 2003. He is a member of IEEE Power Engineering Society and CIGRE Paris. His field of interest includes electrical machines, power transformers, power quality, energy efficiency systems and wind energy systems. Currently he is a Full Professor in the "Ss. Cyril and Methodius University", Faculty of Electrical Engineering and Information Technologies, Skopje, Republic of North Macedonia.*

e-mail: krste@feit.ukim.edu.mk

Received on: 18.10.2022

Audio restoration of dubplates: cleaning and digital processing lacquer records from reggae/dancehall culture

Jeremy Blades, Dr Karl O. Jones, Colin Robinson

This paper discusses the cleaning and digital restoration of lacquer records from the Reggae/Dancehall culture known as Dubplates. The paper evaluates the use of certain digital restoration tools used in the processing of the digital audio file. It also discusses the merits of using household goods in the cleaning of these records. The paper also evaluates the use and overuse of certain digital processing tools. This paper is intended to educate laypeople to save these artefacts from further deterioration, and to interest people who are familiar with Reggae culture as well as those who are interested in audio restoration.

Keywords – Audio Restoration, Digital Restoration, Dubplates.

1. Introduction

The archiving of legacy audio formats is an activity that has been recognised as important for many years. Institutions such as the US Library of Congress and others have been participating in this process for many years to save sounds that represent the many different cultures and peoples of the world for future generations to enjoy, appreciate and study [1]. This process obviously varies depending on the media being preserved, however the digitising and digital processing of said media is largely the same. The United States Library of Congress [2] suggests a sample rate of 96 kHz/ second and a bit rate of 24-bits to future proof the digital file and allow for detailed digital restoration. Since the digital files for these legacy formats are relatively large, it leads to the question 'which pieces of legacy media should we be saving?'.

Along with the issues with finding legacy playback equipment and physical deterioration the materials, the question of which media is more important to process is a complicated one. Although the endeavour is to save every piece of audio on legacy formats, this is not something that is currently possible owing to the loss of playback equipment, fatal deterioration of the media and lack of sufficient digital storage space [1]. Furthermore, deciding which specific media to restore digitally also brings up ethical issues such as what is important to society to keep versus what is not [3]. Legal issues regarding copyright ownership can also create problems for restoration laboratories if artists, media owners or other interested parties do not agree to the processing [3].

There are several reasons for not digitally restoring a specific piece of legacy analogue media. Arguably, the most important reason is the pre-existence of a digital copy of the audio with a high enough bit and sample rate. As stated, storage space in the digital domain should always be considered. Taking this idea into account, if the audio held on a specific piece of analogue media exists in another format that has fewer negative issues (such as playback equipment availability and/or physical condition), it would be pragmatic for the restorer to digitise the audio on the less problematic format. For example, if there is a specific song that is to be digitised, it would be better for the restoration engineer to transfer the original multitrack tapes over the vinyl version of the audio because the options for digital processing are greater using individual instruments or stems, especially if the vinyl is damaged and would require extensive physical restoration.

However, where certain tracks are being digitised to preserve the overall mix version (such as a remix by a certain producer), the vinyl would be the preferred [4]. In these instances, it is the art of the producer or mix engineer that is being preserved. In an ideal situation, both would be transferred, however digital storage space could, again, become a problem.

2. History of dubplates and reggae sound systems

Sound Systems (or Sounds) have been an integral part of the Jamaican music scene since the 1940s when they were employed to play music in clubs instead of live bands. There were two main reasons for this: firstly, the appetite of the audience in the dancehalls at the time was leaning more towards the

new music coming out of America on vinyl and shellac discs. This meant that local live bands usually could not keep up with audience demand for this new American music where Sound Systems, could import the newest music and play it. Secondly, live musicians were much more expensive to promote, whether it was a band being flown into the country to play or a local live band. Sound Systems, at the time, employed fewer people than a live band.

The way that Sound Systems differentiated from each other was, firstly and most importantly, by what music they played. Owners of Sounds would go to great lengths to get the newest and most exclusive records they could, often flying to America or using mail orders to achieve this. This meant that only those with the financial means would have a public following. It was also a very secretive affair as many Sounds would go to great lengths to hide what music they had. This was so that other Sounds could not simply look at the label of the record and purchase their own copy [5].

A sound system, historically, is made up of many parts and members, each of which has a specific role. Firstly, there are the physical parts such as turntables, amplifiers, and speakers, which can be used to specifically characterise a Sound. Everything from clarity of the sound, to what it looks like when stacked can be the difference between whether a Sound has a following or not. Each Sound historically would have its own set of equipment, some emphasising bass, others clarity, while others still would focus on the higher end of the frequency spectrum (Fig. 1). This would lead to vastly different speaker constructions, amp selections, placement, and stack structure. This whole system was usually controlled and set up by the 'Box man' or 'sound man'. Other members of the collective include the ‘Selector’ who chooses the music that will be played. The ‘Mixer’ who actually plays the tracks selected and the ‘Deejay’ who is the voice of the sound [5].

The secrecy around the music owned by a Sound continued into the next phase of Sound culture. In the early 1960s, when Jamaican music was being played far more often than the American Rhythm and Blues or Jazz from the previous era, promoters and owners of Sounds began expanding into record production. The use of the lacquer master records from the vinyl production process became a vital part of any Sound. These records (known as Dubplates) were played in the dancehall to gauge crowd reaction to a new production. This way, as record production materials were scarce in Jamaica due to expense, the producers would only commercially press the tracks they knew would sell. Dubplate cutting studios became more prevalent, often run by a single person who was the mastermind of how the dubplate was cut. Again, these methods were often a closely guarded secret as the cutting studios would also be in competition with each other. The cutter would also be able to adjust his methods so that the dubplate sounded its best when played specifically on a Sound's box. As the boxes were all so radically different, it meant that each dubplate produced could possibly have its own signature EQ curve applied to it [6].

Fig. 1. The “Richochet Sound System (Bermuda)” in front of their Box.

As time and technology has moved on, the use of the lacquer disc for these 'dubplate specials' has become less prevalent, with Sound Systems moving to digital media, resulting in the lacquer dubplates being placed into long storage and/or simply forgotten.

3. Overview of the restoratoin process

When creating a workspace for audio restoration there are several pieces of equipment required, as well as an adequate space. Once a suitable digitising station, peripherals and space are obtained, one can turn their efforts to finding appropriate equipment for playback of the legacy formats to be restored since the media is, in essence, obsolete thus playback equipment is also disappearing.

3.1. Workstation

The workstation for the restoration should consist of a suitable computer, audio card, monitors and headphones. An illustrative set is given in Table 1.

These pieces of equipment should be, at minimum, able to run an application for the ingestion of audio without losing any data. It must also have an adequate amount of storage since file sizes involved in restoration can be large. The audio card should be able to ingest at a rate of 96 kHz and a bit depth of 24-bits at line level [1].

Table 1. Example Restoration Set-up

	Manufac-turer	Specifications
Computer	Apple Mac Mini (2018)	**Processor:** 3GHz 6-Core Intel Core i5 **Memory:** 32GB 2667 MHz DDR4 Storage: 1TB SSD **OS:** MacOS Catalina version 10.15.7
Digitiser	Focusrite Scarlett 2i2	**Supported Sample Rates :** 44.1kHz, 48kHz, 88.2kHz, 96kHz, 176.4kHz, 192kHz Frequency Response: 20Hz- 20kHz ± 0.1dB **THD+N:** <0.002%
Headphones	Beyerdyna mi DTT770 Pro (80 Ohm)	Frequency Response: 5-35,000Hz Nominal T.H.D.: <0.2% Ambient noise isolation: approx. 18 dBA Transducer type: Dynamic
Monitors	Alesis M1 Active 520	**Design:** Bi-amplified Design /Tweeter - 25W, woofer - 50W **Frequency Response:** 56 Hz-20 kHz **Signal-to-Noise Ratio:** >100 dB below full output, unweighted **Input Sensitivity:** 85 mV noise (pink) produces 90 dB(A) output SPL at 1 meter. Gain knob turned fully clockwise (maximum)

The main characteristic that any output device requires is transparency - the speaker or headphone do not add extraneous frequencies to the audio output. If this is not possible, then knowledge of the limitations of the output device should be readily available.

3.2. Equipment for grooved disc restoration

For restoration of grooved discs, the equipment required is easily sourced owing to the resurgence or vinyl sales. However, when obtaining the relevant equipment there is a need to refer to the media to be restored. Similar is true for styli that tracks the groove. The groove widths on discs can vary, so it is important to have styli available of varied diameters and shapes. This will ensure the best possible signal. There are 4 main shapes of stylus defined by their shape [7]:

- Spherical: Cheapest and most durable of shapes, but generally least accurate.
- Elliptical: Less durable, but more accurate than spherical.
- Hyper Elliptical: Better output quality, although more expensive than elliptical.
- Micro-Ridge: Most accurate and most expensive.

A second important stylus characteristic is the needle tip. These tips are generally made from diamond because it is a hard-wearing material. For vinyl records from the 1950s onward, when the microgroove became standard, tips are required to be between 1 and 3 millimetres in diameter [7].

The next part of the chain for playing vinyl is the turntable, for which there are several characteristics to be accounted for. Everything from the shape of the tone arm to the noise the motors make can change the signal produced. There are 3 main parts of the turntable: the tonearm, the platter and the plinth. The plinth tends to be made from a dense material to avoid resonance that may be picked up by the stylus.

There are 3 main shapes of tone arms, S-Shaped, J-Shaped and Straight. S- Shaped tone arms are slightly longer and hence have more mass than straight tone arms. There are negligible differences between these tonearms once they are correctly set up and balanced. The platter is what the record sits on and spins in order for the stylus to track the groove. There are 2 main ways which platters are turned: direct drive turntables use gearing to directly connect the motor to the platter, and belt drive turntables that use a belt to connect the platter to the motor. Direct drive turntables are also less susceptible to fluctuations in platter speed. In contrast, belts can wear out, causing platter speed fluctuations, although the advantage is the motor can be further away from the platter which means less motor noise is audible through the stylus. Another characteristic of belt driven turntables is a heavier platter which helps to avoid audible jumps and skips.

Turntable usage also takes into account other considerations. One of these is where the turntable is set up. Turntables are susceptible to outside stimuli which can affect output. Generally, for optimum output, they should be placed on a flat, dense platform that is isolated from power cables and physical vibrations. Measurable characteristics such as wow, flutter and rumble should have low values when choosing a turntable.

Another piece of equipment necessary for grooved disc restoration is a preamplifier which is necessary when playing vinyl since the output produced by the stylus is much lower than line level (normally approximately 0.005V versus 0.3V respectively) [7]. Table 2 illustrates typical equipment. Some amplifiers and turntables have built in preamplifiers to overcome this problem. For restoration, this can be the source of an issue because many inbuilt phono preamplifiers employ the RIAA (Recording Industry Association of

America) EQ curve [8], which has been standard for vinyl since 1950. For restoration, it is important to have a phono preamp with a flat EQ setting, because prior to the adoption of the RIAA curve as standard, each record company employed its own bespoke EQ curve for their releases. Applying an RIAA curve to some records may result in incorrect frequency reproduction. This is similar to the Dubplate cutting studios employing their own curves for specific cuttings. The possibility of removing the RIAA curve from the output signal can improve the digital processing that may occur later [6].

Table 2. Example list of equipment.

	Manufacturer	Specifications
Turntable	Audio-Technica AT-LP120XBT-USB	Drive Type: Direct Drive Speeds: 33 1/3, 45, 78 Outputs: Phono Level, Line Level Wow & Flutter: <0.2% (WTD) @ 3 kHz Signal-to-Noise Ratio: > 50 dB
Stylus 1	Ortofon 2M 78	Spherical Type: Moving Magnet Tip Radius 65 µm Tracking force, recommended: 1.8 g Frequency Response: 20-20.000 Hz +3 /-1 dB Speed: 78 RPM
Stylus 2	Ortofon MC Quinet Blue	Nude Elliptical Type: Moving Coil Tip Radius: r/R 8/18 µm Tracking force, recommended: 2.3 g Frequency Response: 20-20.000 Hz +/-2.5 dB
Preamp	REK O KUT Ultra Phono Preamp	Curves: Flat, RIM

3.3. Software

To properly restore the digital files, ingestion of the analogue audio must take place. There are several software options for this and the processing of the audio. It is a good idea to have more than one option for processing as many applications have their own unique strengths. This work used Izotope RX8 Advanced (isotope.com) which provides a spectrograph of the audio file making it simpler to see where audio defects occur within the frequency spectrum.

3.4. Logging procedure

Logging vinyl for restoration purposes needs care and preparation. Some of the important information to be held on this form are [9]:

Date of release: This gives vital information about how it was produced, leading to details such as the composition of the physical record and probably groove widths. This will help with stylus choice as well as the probability of RIAA curve use in production.

Label (Record Company): Knowing which label released a particular record will inform which playback curve may be in use. Before the RIAA curve became standard, each label had their own curve [6].

Cleaning: The method of cleaning used should be recorded.

Digital Transfer Details: Currently, standard practice widely accepted is that analogue materials are ingested at 96 kHZ sample rate and 24-bit depth.

Equipment Used: Each piece of equipment used in analogue restoration adds its own characteristics to the end result file.

RPM: Both the intended RPM and the RPM used at ingestion are recorded [10]. It is possible to ingest at a lower RPM if there are defects on the record that will cause inaccurate groove adherence. The slower speed will give the stylus a greater chance of staying in the groove and picking an accurate audio signal. The digital file can then be adjusted using software.

3.5. Care, storage and maintenance of grooved format discs

3.5.1. Storage

Care of vinyl records begins with storage of the media. Since these records are susceptible to certain environmental fluctuations, it is important to store them in appropriate places [11]:

- **Cool:** Rooms holding vinyl records should be relatively cool to avoid damage from heat. For long term storage, recommended temperature should be 8°C to 12°C, for short term storage the room should be lower than 20°C [1].
- **Dry:** By 'dry' it is understood that the storage facility should be between 30% and 50% relative humidity for short term storage, and 25% to 30% humidity for long term storage.

3.5.2. Care

The care of vinyl can be relatively simple if storage concerns are heeded. There are two main ways of cleaning, wet cleaning, and dry cleaning. As the names suggest, one involves liquid cleaning solutions, and one does not. The main characteristics of any cleaning method should be that they are:

- **Non-abrasive:** Brushes, cloths and other cleaning materials should not create scratches or marks on the surface the vinyl which can lead to audible defects in the playing surface.
- **Chemically inert:** The cleaning product, especially any solution used, should not react with the playing surface of the record. Some solutions can break down the chemicals in the record leading to deterioration of the vinyl.

- **Leaves no residues or liquids:** The cleaning process should leave the surface dry and free of residue when complete. This could lead to further contamination and audible defects when played back [1].

Dry cleaning is relatively simple and should be the first method used, especially on physically damaged records. Cleaning should happen in a circular motion, following the grooves of the record, from inside (nearest the label) to outside (edge of the record). Fig. 2 illustrates dirt removed from a Dubplate.

Wet cleaning involves the use of water or a cleaning solution. Any water used should be distilled and/or deionised water. Selection of which cleaning solution should be dictated by the composition of the record to be cleaned. The chemical makeup of these solutions should always be checked before use. Cleaning machines can also be employed. Keith Monks machine (keithmonks-rcm.co.uk) which wet cleans and then removes remaining surface liquid by vacuum, is recommended. Ultrasonic machines should be avoided on cracked or broken vinyl, but for structurally sound media it can be especially useful. Always be aware of static charging and dissipate any static held by the record before playback or storage [1].

Fig. 2 Dirt removed from a Dubplate.

4. Methods and results

4.1. Collection

The materials used in this work were collected from Sound System members personally known by the first author, ensuring as much information could be collected about the records, such as year of cutting, storage methods, and often the name of the engineer who cut them. The two specific records discussed here were chosen according to criteria, as suggested by McCoy-Torres [12]:

- Records the owners wanted digitised
- Records of artists now deceased
- Records having either no digital version or a low-quality one

4.2. Digital ingestion and cleaning

Each chosen record was, once photographed, immediately digitally ingested. The equipment used for this was an Audio Technica LP120 turntable with an Audio Technica VM95E (bonded eliptical) stylus. The turntable platter was deadened using an NAO Acoustic Isolation Mat. A Focusrite Scarlett 2i2 audio card was used to convert the signal from the turntable's internal preamp which was set at the standard RIAA position. The digital file was captured using Audacity (audacityteam.org). The turntable levels and balance were tested using a HiFi News Calibration record (hifinews.com), providing a thorough check of the frequency response, input levels and input balance before digital transfers occurred. The turntable tonearm was also balanced to ensure accurate tracking forces would be applied.

4.3. Playbwoy sound dubplate (elephant child specials)

This record was chosen because the artist was murdered in 2013, leaving the dubplates as part of his legacy. The record was in a relatively good condition when received having been stored in relatively well. It was dry cleaned using a dry cloth normally used for cleaning glass, removing most of the loose surface contamination. Each side of the record was then played from lead in to lead out groove at its correct RPM of 45 RPM. The digital file was captured at 96 kHz and 32-bit in Audacity. The resulting audio file was then exported as a .WAV file. A log sheet was then created with all relevant details of the record and audio file. The record was then wet cleaned using generic paper towels, boiled water and three drops of dish washing detergent, resulting in more surface contaminants being removed. Once wet cleaned, the record was ingested a second time using the same methods and settings as previous. A second log sheet was created for this audio file. The digital files were then subjectively compared audibly to decide which version had fewer audible defects. It was decided that the second pass was audibly cleaner.

4.3.1. Track 1: '*Hail*'

The first track to be processed in lzotope RX8 was '*Hail'*. The spectrographs pictured shows the unprocessed initial version of the track's first and second passes. The noise on the track is especially visible at the beginning of the file (left side of Fig. 3). This view confirms that the second pass (after cleaning) has less surface noise present and should be used as the basis for any further processing. Once the file was imported, the first process applied was the De-click function to remove as many audible clicks

and pops as possible without affecting the true audio signal. The next process used Spectral De-noise which works by learning the profile of the background noise and subtracting it from the signal. Overuse of this process had a negative effect on the true audio signal as it attempts to remove a wide band of frequencies that are interpreted as noise. This process was undone and repeated several times to get to a, subjectively, reasonable outcome. Fig. 4 shows the intensity of the noise at the beginning of the track being greatly reduced. The next function employed used was Center Extract which is designed for stereo files that have been derived from a mono file. Generally, it suppresses the 'outsides' of the track which is generally where extraneous sound resides in mono tracks transferred using stereo styli. Interestingly, using this function sparingly on '*Hail*' produced an audibly cleaner version of the file. Arguably, use of this tool on a stereo file can remove too much of the ambiance of the track, however very light use produced a more useable version of the audio file. It was at this point it was noted that the track was lacking much of the higher end of the frequency spectrum. The owner of the dubplate was contacted to find out more details about the record, who stated that it was a popular track and thus played often. This led to degradation of the groove and hence the 'muddy' playback. It is also possible that some of the processing may have removed some of these higher frequencies. It was decided that processing would stop at this point since the majority of the background noise was removed and, although not perfect, the vocal could be heard clearly.

4.3.2. Track 2: '*Pray Everyday*'

The next track to be processed was '*Pray Everyday*'. Again, it was noted after comparing both the audio files and spectrograms of each pass, that the second pass had less surface noise in its unprocessed state, thus this was chosen for further processing. As with '*Hail*', the first process used was the De-click function, removing the majority of the audible clicks and pops. It was noted that the audio file contained a hum between 97 Hz and 101 Hz. Since the ingestion equipment had been calibrated before digital transfers occurred, and did not show any extraneous frequencies, the source of the noise was unknown. It was not part of the track itself since no other noise is present. In order to remove it, the spectral de-noise function was trained around that frequency and lower and performed on the track. This process succeeded in removing the most of this extraneous noise. A second spectral de-noise was used to remove as much general surface noise from the audio file. Again, this was a trial-and-error process to balance removing noise and adversely affecting the true audio signal.

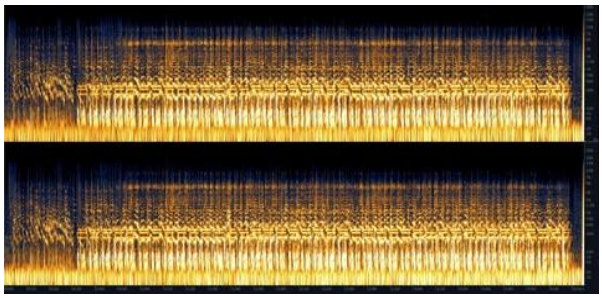


Fig. 3. Second pass spectrogram of 'Hail'.

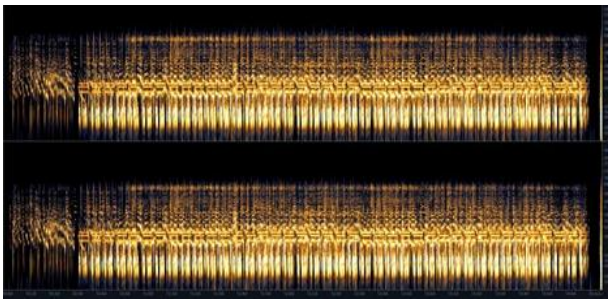


Fig. 4. Spectrogram of 'Hail' post center extract (final track version).

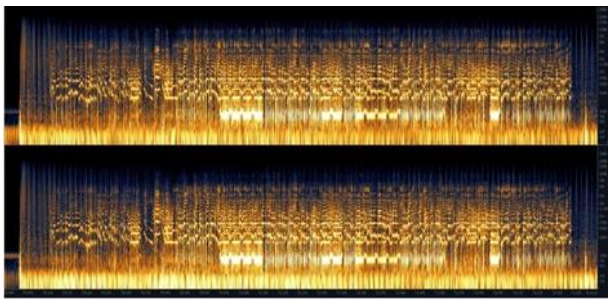


Fig. 5. Second pass spectrogram of 'Pray Everyday'.

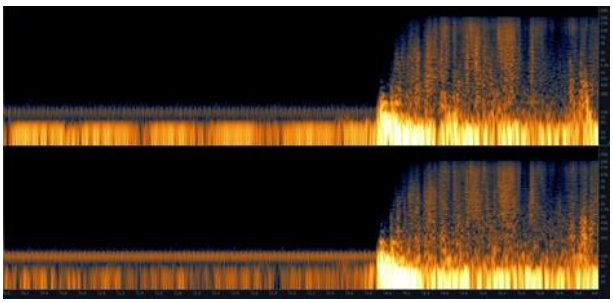


Fig. 6. Enlarged screenshot of low frequency hum on 'Pray Everyday'.

4.4. Deathmark sound dubplates

The track selected was performed by Monty Gallis and Kojah Mon. A duo from Bermuda who no longer perform together. It was recorded over 20 years ago in a home studio in Bermuda and cut in Florida from DAT tape. The cutting process remains unknown. This record was in far worse condition than the Elephant Child Dubplate, with severe damage on the leading edges which appeared to be missing pieces of the lacquer coating that makes up the playing surface of the record (Fig. 7).

Fig. 7. Damage to the 'Kiss From A Rose' dubplate, with magnified section.

The record had been stored badly initially as well as played many times, so it was expected that the audio held would be poor condition. However, it was unknown how well the initial recording sounded as the DAT has disappeared. Because of this, it was important to digitally capture the track as they exist nowhere else. The dubplate was digitally ingested in the same fashion as the Elephant Child dubplate. However, as the grooves on this record was in worse condition, the transfer speed was dropped from 45RPM (the intended playback speed) to 33⅓RPM to increase groove adherence by the stylus. Audacity has a function in its effects menu (Change Speed) that will adjust the speed of the audio file transferring it up from 33⅓RPM to 45RPM, thus returning the audio file to its intended playback speed.

4.4.1. Track 1: '*Kiss From A Rose*'

This track brought up the question of whether to remove the RIAA curve put onto the audio by the preamp in the Audio Technica turntable before processing in lzotope RX8 would begin and replace it after processing. It was found by comparison (audibly) that removing this curve would not only boost the high frequency defects on the track, but also hid any rumble or other low frequency defects [13]. It was thus decided that the RIAA curve would stay in place as it sounded, subjectively, better. The track was ingested at the lower speed of 33⅓RPM and processed in Audacity to correct the playback speed. The RIAA curve was removed before this and replaced after it was completed to avoid incorrect frequencies being processed. As with the 'Elephant Child' dubplates, it was found that the digital file created after wet cleaning was less contaminated and thus was used for further processing in RX8 (Fig. 8). The first process undertaken was de-clip, processing any clipping in the track and interpolating the relevant wave forms to be less square. De-click was then used to remove many unwanted pops and clicks. Spectral de-noise was applied to remove unwanted surface noise that had been ingested with the audio. This process left a few unwanted noises on the audio file. The centre extract tool was used at this point to attempt to remove these artefacts (Fig. 9). Interestingly, this seemed to make the noise levels, subjectively, acceptable although it was a compromise as there was also a loss of atmosphere in the track. The track was then normalized, which increases the gain on a track so that its peak level reaches a target peak level.

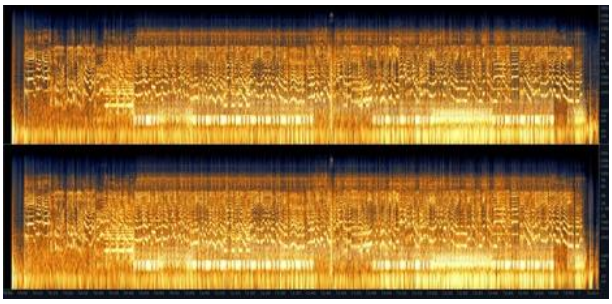


Fig. 8. Second pass spectrogram of 'Kiss From A Rose'

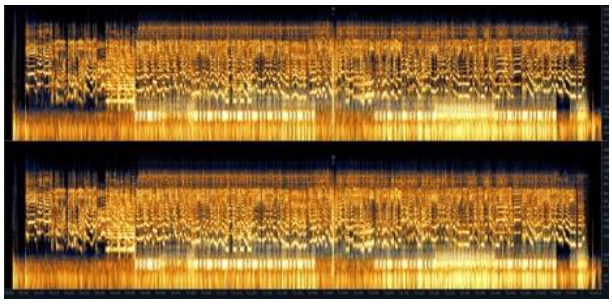


Fig. 9. Final version spectrogram for 'Kiss From A Rose'.

5. DISCUSSION

5.1. Cleaning methods

This work used simple household solutions to the problems of cleaning, since this will be useful to Sounds that do not have access to cleaning machines or commercially available cleaning solutions. Although the results from the cleaning methods for this project were somewhat successful, there are many ways to improve this process and its outcomes, such as discussing options with chemical scientists to analyse the contaminates found on the lacquer surface.

5.2. Turntable and stylus

The turntable used for this project was an excellent, home use turntable. It is designed for home applications and as such it is on the lower end of professional restoration applications. Although the platter was deadened on the turntable, higher end turntables would have better noise related specifications. This project lacked, at very least, stylus options which made it difficult to gauge if a different stylus might have produced a better output. To avoid over processing, future experiments must use this comparative method of stylus choice.

5.3. Preamplifier

Leading on from the turntable and stylus discussion, a flat preamp may have been useful for this work. One of the issues with grooved recordings is that low frequency signals create larger grooves which can cause the stylus to leave the groove [13]. In many situations, Dubplates were recorded in situations that were not conducive to audio recording. This meant that microphones, mixing desks and other recording equipment may have been less than optimal for the intended purpose. When attempting to digitally restore a dubplate, it is unlikely that it will have had the RIAA curve applied to it. In essence, by applying the playback RIAA curve as undertaken here, there may be the addition of extraneous frequencies or an untrue representation of what is actually on the record.

5.4. Software processing

Once the dubplates were committed to the digital domain, processing to remove unwanted noise began. This processing was hampered by the issues raised in the previous section. It is important when processing to know how far to push and when to stop. Over processing leads to distortion in the audio signal as well as loss of frequencies fundamental to the audio file. Audacity has powerful effects within it and an especially useful filter curve effect, including the RIAA curve and many other pre-1950 EQ curves. This program was used, in this work, as the capture program for digital ingestion. It was also used to change the playback speed of tracks that were ingested using a slower than intended RPM.

The interface for RX8 Advanced can display either the waveform of a track or the corresponding spectrogram. This is useful since it provides a visual representation of the energy at each frequency level. This is displayed by colours ranging from orange to white. RX8 is intuitive, however one must beware of over processing while using any of the many functions within the program. In this work, extensive use was made of the spectral de-noise function, to remove any unwanted broadband and or tonal defects from the audio signal. This function requires a large amount of finesse as it is possible to remove or suppress frequencies from the true audio signal. Another tool used in this project was the center extract plug-in. Although not designed for use with stereo tracks, this plug-in was used to remove extraneous noise from tracks with relative ease. However, there was a compromise when using this tool. It was very easy to remove atmosphere and depth from a stereo track with this tool. As it was designed primarily for use with mono tracks imported using stereo equipment, the algorithm seeks similarities between the left and right channels and endeavours to remove any noise that is not similar. When overused while processing the dub plates for this project, it was noticed that some reverb was removed along with the noise that was being

targeted. These issues aside, the program is extremely useful in the right circumstances and with the right supporting equipment.

5.5. Subjectivity versus Objectivity

One of the biggest obstacles faced was the question of when to stop audio processing. Regardless of software being used, it is quite easy to overdo the processing of a file. This is not the over processing previously mentioned, but instead the search for perfection in the processing. When digitally restoring an audio file, regardless of medium or genre, it is important to know when the file is 'good enough'. However, the definition of this varies depending on if one looks from a subjective or objective point of view. Something perceived as a flaw in an objective observation may be pleasant to the listener and thus should not be removed. The question with restoring dubplates could be as simple as '*how much of surface noise should be left in the mix*'. Many people enjoy the sound of the crackle associated with grooved recordings. Just as the cutter and their client may discuss how much bass to add to the dubplate they are producing, it is important to keep in mind who the end product is aimed at. Grooved media is enjoyed by many because of the warm harmonic distortion that accompanies it. Fundamentally, it has to be understood what the purpose of the restoration is.

6. Conclusions

The novelty in this work has been the bringing together of a number of aspects, such as signal processing, cleaning, audio signal processing processes and so on, to formulate a proposed methodology for restoring dubplates from the Reggae/Dancehall culture of the West Indies.

At the end of this work, several lessons have been learned. The limitations of certain methods of cleaning dub plates were discovered however, it was also found that very basic household items can be used effectively when attempting to remove surface contaminants. Given that over-the-counter vinyl cleaner is detrimental to the lacquer layer of the dub plate showed that non-solvent-based solutions must be used. The process of restoring a dubplate is not one that can really be automated since a fundamental element of the process is for the operator to undertake the cleaning process by hand to ensure that damage is not caused to the dubplate, and for the operator to continuously listen to the track and make a professional (and partially personal) judgement on whether an action undertaken in the audio processes stage had improved the listener's experience or not – something that an automated process cannot achieve at the moment owing to its very subjective nature.

When digitally ingesting materials it is paramount that the best equipment available should be sought. It is also important to ensure that all maintenance has taken place on both the equipment and on the records before ingestion takes place, making it easier to remove any remaining surface noise in software. Software is a powerful tool in the world of restoration. In the past, much of the processes we now have access to by the click of a button, was only available in hardware and was relatively expensive. Now, with the technology available, it is possible for Sound men to perform these digital transfers in the comfort of their own homes if they have the minimum equipment available. This is a useful idea when it comes to dub plates as many of the smaller Sounds may not have access to full professional restoration equipment. However, as the Technics SL-1200 and its derivatives are one of the most robust and prevalent turntables in the world, it is possible a layman could perform basic digital ingestion and basic processing on a dubplate that may have been in storage for many years.

As with all audio restoration and archiving, it is important not to waste either time or space in the digital realm on unnecessary transfers. One should endeavour to transfer those artefacts that are in the most danger of fatally deteriorating. It is always important to evaluate the media you intend to transfer and ensure it is the best choice for digital transfer.

Dubplates (in their lacquer form) will eventually become impossible to play, as their design was not meant to last very long or even be played very often. Many of these records have already disappeared owing to storage issues and accidents. They are more fragile than vinyl records and as such should be treated with the utmost care and attention. They are also representative of a culture that has expanded around the world and has been deemed worthy of protection by the United Nations.

This article is presented at the 36th International Conference on Information Technologies (InfoTech-2022), IEEE Conference, Rec. # 55606, September 15-16, 2022, Bulgaria.

REFERENCES

[1] Brylawski, S., Lerman, M. Pike, R. and Smith, K. ARSC guide to audio preservation. Pittsburgh: Association for Recorded Sound Collections, 2015.

[2] Carneal, R.B. The Operation of the Recording Laboratory in the Library of Congress. Library of Congress, Washington, Paper 629, 1968.

[3] Rumsey, F. Preserving our audio heritage. Journal of the Audio Engineering Society, Vol. 66(10), 2018, pp. 852-856.

[4] Copeland, P. Manual of analogue sound restoration techniques. London, UK: British Library, 2008.

[5] Chamberlain, J.R. So special, so special, so special: citizenship, nation and the Jamaican sound system. PhD Thesis, the University of the West Indies, 2020.

[6] Moyer, R.C. Evolution of a recording curve. Audio Engineering, Vol. 37(3), 1953, pp. 19-22.

[7] Barlow, D.A. Comments on "On Stylus Wear and Surface Noise in Phonograph Playback System". Journal of the Audio Engineering Society, Vol. 4(3), 1956, pp.116-119.

[8] Lipshitz, S. P. On RIAA Equalization Networks' Journal of the Audio Engineering Society. Vol. 27, No. 6, 1979, pp. 458–481.

[9] Cohen, E. Digital libraries, preservation, and metadata. Journal of the Audio Engineering Society, Vol. 49(7/8), 2001, pp. 587-588.

[10] Kuhnle, P., Hatje, U., Kummer, J.C. and Musialik, C.M. An Integrated Solution For Digitization, Archiving, And Restoration Of Large Audio Collections. In Audio Engineering Society Conference: 20th International Conference: Archiving, Restoration, and New Methods of Recording. Audio Engineering Society, October 2001.

[11] Farrington, J. Preventive Maintenance for Audio Discs and Tapes. Notes, Vol. 48(2), 1991, pp.437-445.

[12] McCoy-Torres, S. Just Ask Mi'Bout Brooklyn: West Indian Identities, Transgeographies, And Living Reggae Culture. PhD Thesis, Cornell University, USA, 2015.

[13] White, S.J. The Problems of Low-frequency [Sound] Reproduction. Journal of the Audio Engineering Society, Vol. 1, 1952, pp. 20-49.

Jeremy Blades – *School of Engineering, Liverpool John Moores University, Liverpool, United Kingdom. Jeremy completed an MSc in Audio Forensics and Restoration at Liverpool John Moores University in 2022. His interest is in audio restoration particularly related to cultural heritage in his native Bermuda, and the West Indies in general.*

e-mail: Jfblades@btinternet.com

Dr Karl O. Jones *- School of Engineering, Liverpool John Moores University, Liverpool, United Kingdom. Karl completed his BEng in Electrical and Electronic Engineering at Liverpool Polytechnic, and his PhD at Liverpool John Moores University. His research interests are Evolutionary Computation, Artificial Intelligence, Control Engineering and Audio/Video Forensics.*

Tel: +44 (0) 151 231 2199 e-mail: K.O.Jones@ljmu.ac.uk

Colin Robinson - *School of Engineering, Liverpool John Moores University, Liverpool, United Kingdom. Colin completed his BSc in Broadcast and Media Production at Liverpool John Moores University. His research interests are in Audio Restoration, Audio/Video Forensics and Engineering Education. Colin has worked with people such as BBC TV presenter Sir David Attenborough and internationally renowned educationalist Sir Ken Robinson. Colin has also been used as an expert advisor for a number of TV documentaries.*

e-mail: C.Robinson1@ljmu.ac.uk

Received on: 24.10.2022

Approach in measuring nasal cavity and PNS volume

Lachezar Lichev, Viktória Hránková, Michaela Masárová, Jakub Lubojacký, Petr Matoušek

With the method and approach developed within the Fotom module, the results obtained are comparable to other volumetric instruments (e.g. OssiriX). This software product is free, easily accessible and applicable in healthcare facilities around the world, unlike other systems that are expensive and often tied to a specific platform, such as the currently available Osirix software. Photogrammetry software can be widely used in otolaryngological practice. One possible use is to measure the nasal cavity and paranasal sinuses (PNS) volume. Knowledge of the development of PNS, anatomy and volume is crucial for the management of pathologies in this area. The importance of knowledge about the volume of the PNS and nasal cavity and their development lies in the great individual variability in the level of their pneumatization and the actual size of the skull. In addition, the establishment of PNS and nasal cavity volume as a standard part of preoperative radiological examination may contribute to the safety and efficacy of endoscopic sinus surgery and transnasal skull-based surgery.

Подход за измерване на обема на носната кухина и параназалните синуси (PNS) (Иван П. Георгиев, Асен Х. Димитров, Елена Г. Тодорова). *С метода и подхода, разработен в рамките на модула Fotom, получените резултати са сравними с други обемни инструменти (напр. OssiriX). Този софтуерен продукт е безплатен, лесно достъпен и приложим в здравни заведения по света, за разлика от други системи, които са скъпи и често обвързани с конкретна платформа, като наличния в момента софтуер Osirix. Софтуерът за фотограметрия може да се използва широко в отоларингологичната практика. Една възможна употреба е за измерване на обема на носната кухина и параназалните синуси (PNS). Познаването на развитието на PNS, анатомията и обема е от решаващо значение за управлението на патологиите в тази област. Значението на познаването на обема на ПНС и носната кухина и тяхното развитие се крие в голямата индивидуална вариабилност в нивото на тяхната пневматизация и реалния размер на черепа. В допълнение, установяването на PNS и обема на носната кухина като стандартна част от предоперативното рентгенологично изследване може да допринесе за безопасността и ефикасността на ендоскопската хирургия на синусите и трансназалната хирургия на черепа.*

Introduction

As for the clinical significance of computed tomography (CT) volumetry for otorhinolaryngology, such studies of paranasal sinuses are quite rare. Most of the volumetric studies are historical and were performed on the cadaver skulls – the volumes of PNS as stated both in textbooks and scientific articles are still cited from these historical publications. Modern studies using CT scans usually do not examine more than a few dozens to hundreds of subjects. Therefore, new studies with more subjects are needed to determine the average volumes of PNS throughout different populations and groups of individuals as to age, sex and ethnicity. Particularly in pediatric population, just as the "traditional" sources claim, it is believed that some of the PNS are lowly pneumatized or are not developed at all in young age, mainly in case of the frontal sinuses. However, newer studies show that this might not be true and that for example small frontal sinuses might be present even in infancy. This is significant for the clinical praxis because of indication of CT or MRI (magnetic resonance imaging) in pediatric population in certain suspected pathologies in the area of the PNS and nasal cavity.

Data collection

The study was performed on a dataset consisting of 30 randomly selected patients. These photos were taken by the University Hospital in Ostrava. In the

images, we found jaw cavities, wedge-shaped cavity, frontal cavity and ethmoid cells.

The volumes of these cavities were measured using the FOTOM system and, for subsequent comparison, the OsiriX system.

Methods

Implementation

The FOTOM software is used for digital image processing. Since 2000 it has been developing in the Department of Informatics, VŠB – Technical University of Ostrava Faculty of Electrical Engineering and Computer Science. The initial focus was on measuring mine pits. The system has a modular structure that allows easy expansion of its use for biomedical image analysis. Currently FOTOM consists of the following modules:

1. Fotom01 - used to define objects of interest. These objects are defined using a set of points that is used to plot the Bézier curve [4]. It also supports volume and area measurements and subsequent export of these values in graphs and tables. Using this output, it is possible to easily observe the changes in these values within a series of images, as well as to determine the resulting volume and content of the observed object [5, 10].
2. Fotom02 - allows 2D modeling of objects [5, 10].
3. Fotom03 - allows visualization of a series of 2D images in a voxel model [5-11].
4. Fotom04 - allows you to create an animation from a series of 2D images [5-10].
5. Fotom05 - allows tracking of the object in a series of images [5, 6].

The results can be seen in Fig. 1.

The Fotom5 module is used to monitor objects. Before using this module, it was necessary to manually select the necessary objects of interest. Given the number of images in the series that contain the object of interest, this approach takes a long time. As part of image pre-processing, the image can be filtered with standard (mean, median, Gaussian) filters. The next step is to determine the threshold value that divides the pixels into object pixels and background. Because a binary threshold is used, pixels can be often wrongly labelled. The user, who has incorrectly defined it in this way, can correct it using the drawing function. The last step was to determine the object of interest. The user determines this by selecting points. After the selection, it is necessary to determine the number of points that define the boundary of the object.

In this approach, it is necessary to repeat the entire above procedure for each image. The advantage of this approach is the high accuracy of cavity determination, but the long time required to simplify this procedure.

The new version of the Fotom5 module uses active contours [8], so it is no longer necessary to define the object of interest in each image in the series separately. This is a more advanced segmentation method. It is based on the action of energy that deforms the shape of the user-defined initialization curve until the curve reaches the shape of the segmented shape.

Parametric active loops were used first. In this case, several energies act on the curve:

The curve is defined by a parametric equation

$$E = E_{ext} + E_{int} = E_{ext} + E_{stretching} + E_{bending} = \\ = -G_{x,y} * \nabla n_{x,y} + \int_0^1 \left(\alpha(p) \left| \frac{\partial s(p)}{\partial p} \right|^2 + \beta(p) \left| \frac{\partial^2 s(p)}{\partial p^2} \right|^2 \right) dp \quad (1)$$

Where:

$-G_{x,y} * \nabla n_{x,y} \ldots \quad E_{ext}$ - potential energy, an imaginary time curve moving in the direction negative gradient, i.e. in places with lower potential energy

s - length of the curve s(p)=(sx(p), sy(p))

p - individual elements along the entire length of the curve.

where at: p = 0 the beginning of the curve,

p = 1 the end of the curve

α - coefficient of elasticity of the active contour curve, α = 1

β - coefficient of smoothness of the active contour curve, β = 0

The results of cavity segmentation alone were satisfactory and the number of required user interactions was also reduced. The time required to process the batch itself has not changed significantly, because the calculation is relatively slow. Another disadvantage is that user must know the method to set the correct input parameters.

Another attempt at improvement was the use of geometrically active loops. Their advantage lies in the segmentation of several objects at once. This reduces the time required, but often, as a result of

segmentation, there are too many detected objects, which requires additional correction.

Due to the unsatisfactory results obtained in the previous approaches, the Fotom5 method was applied. In this version of Fotom, the object is detected using seeds. From the seeds, the area of the object gradually increases until its limits are reached. The resulting object is defined by all pixels belonging to the object.

For proper operation, it is necessary for the user to manually specify the seed for the first and last image of the examined part of the series. We consider these images as reference and do not doubt the correctness of the detection of objects on them. We consider the images between the two reference images as a separate series. If the user creates multiple reference images, each detection error will be limited to this subset and will not be reflected in the others.

The next step is to look for all potential cavities in the remaining images. The points defining the objects in the previous frame are used as seeds of the studied image. Subsequently, the objects are found. The points defining these objects are used as seeds in the next frame.

The result is a set of potential objects of interest.

The next step is to exclude unwanted objects. In this case, the algorithm moves from the last image of the subseries to the first. The points of the object are compared between the currently studied image and the previous image. If an object in the examined image has at least one pixel in the same position as each pixel of any object in the previous image, that object is considered valid. Otherwise, this object is deleted.

The procedure is illustrated in Fig. 2.

In the photo on the left, cavities have been found that will create search seeds in the next photo (photo in the middle). The cavities found will create a set of seeds for the next image (right). The image on the right has a user-validated cavity (green). All cavities coated with this cavity are considered valid (marked in yellow)

The FOTOM program represents objects as a subset of the contour points of an object that are used to draw the Bézier curve. This means that the points must be aligned. The initial attempt to solve them was to arrange them at an angle that they form together. This approach has unsatisfactory results, as it does not work if the contour of the object is not convex.

The improvement is caused by the implementation, in which an arbitrary point is selected from the contour of the object. This point is marked as the start of the journey

One of his neighbors is at the end of the road. The next step is to look for the path between these points. This solution fails if the cavity is formed by two or more larger parts that are connected only by a path whose minimum width 1 pixel. The same problem occurs if a contour contains a "notch" that is only 1 pixel wide. This problem is shown in Fig. 3.

For these cases, the possibility of drawing is preserved, through which he corrects the shape of the object to eliminate these cases. It is also possible to apply changes such as adding or removing objects exclusively to the current image.

The graphical interface is shown in Fig. 4.

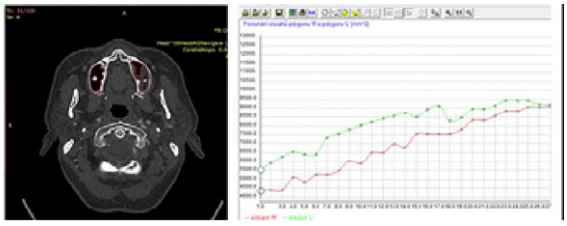


Fig. 1. Outputs of the FOTOM program

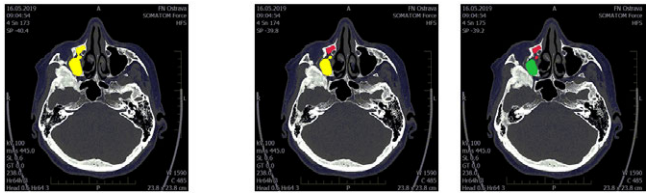


Fig. 2. Red color - cavity found, green color - user-selected valid cavity, yellow color - cavity considered valid

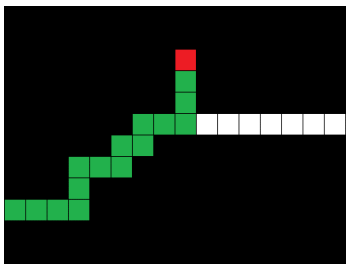


Fig. 3. The green pixels have already been processed. The red pixel is currently being evaluated and must be returned using the pixels already evaluated.

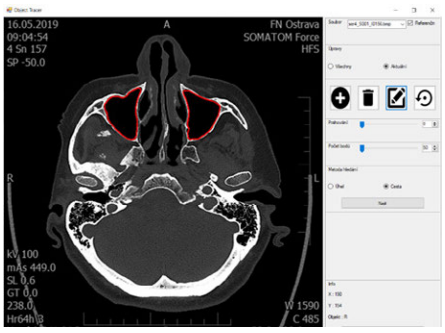


Fig. 4. Graphical interface of the module.

Table 1

Patient	Maxillary sinus [mm^3]	Sphenoid sinus [mm^3]	Frontal sinus [mm^3]	Ethmoid cells [mm^3]
1	10.05	30.07	5.56	9.88
2	8.61	32.82	7.20	8.64
3	5.87	22.81	1.77	9.99
4	34.18	83.65	41.44	15.68
5	16.00	32.77	17.19	9.95
6	12.79	19.85	16.07	8.02
7	7.34	38.17	12.64	9.31
8	8.15	23.69	0.22	6.06
9	16.67	30.56	3.26	8.34
10	10.07	28.36	7.84	9.18
11	13.64	20.06	5.41	5.99
12	0.98	9.82	5.79	4.74
13	2.78	25.27	5.12	2.9
14	3.58	27.68	0.21	4.22
15	10.02	22.98	24.85	3.17
16	9.20	38.58	7.29	9.36
17	8.84	20.49	5.72	5.12
18	15.06	44.08	12.18	8.71
19	11.97	34.84	9.08	10.03
20	16.41	35.93	8.22	4.39
21	12.97	32.90	6.59	7.70
22	10.09	35.87	8.94	5.59
23	6.63	17.52	3.38	5.16
24	12.75	31.70	10.16	9.75
25	9.70	34.90	5.31	7.84
26	15.52	44.24	16.92	9.3
27	9.04	28.82	8.23	6.68
28	4.14	22.90	2.09	6.89
29	14.32	24.67	10.38	7.77
30	8.43	31.62	10.54	6.97

Results

The measurement results were processed at the ENT Clinic of the University Hospital Ostrava and at the Department of Informatics of the Faculty of Electrical Engineering and Informatics VŠB TU Ostrava. The measured values are shown in Table 1.

Head and neck surgeons, especially paranasal sinus and skull base surgery specialists working at the ENT clinic, were able to assess the anatomical proportions of the paranasal sinuses, their volumes and shape, even without the help of radiologists, which could be very beneficial in planning the surgical approach.

This simple and available volumetric tool could be used in various operational fields and research activities.

Our developed volumometric tool, Fotom5, could help improve CT (computed tomography) interpretation of abnormal clinical cases as well as aiding clinicians to develop and select appropriate instruments for medical inspection and treatments.

Discussion

FOTOM^{08} Plus and especially the Fotom5 module is free software for photogrammetry and visualization, developed by the Department of Computer Science, VŠB-TU Ostrava. It applies many modern methods used in measuring, modeling and analyzing and detecting images [5], [18]. The results are comparable to any other software available.

As for the clinical significance of CT volumometry for otorhinolaryngology, such studies of paranasal sinuses are quite rare [12]. Most of the volumometric studies are historical and were performed on the cadaver skulls [13], [14], [15] – the volumes of PNS as stated both in textbooks and scientific articles are still cited from these historical publications. Modern studies using CT scans usually do not examine more than a few dozens to hundreds of subjects [16], [17], [18]. Therefore, new studies with more subjects are needed to determine the average volumes of PNS througout different populations and groups of individuals as to the age, sex and ethnicity. Particularly in pediatric population, just as the „traditional“ sources claim, it is believed that some of the PNS are lowly pneumatized or are not developed at all in young age, mainly in case of the frontal sinuses. However, newer studies show that this not might be true and that for example small frontal sinuses might be present even in infancy [12]. This is significant for the clinical praxis because of indication of CT or MRI (magnetic resonance imaging) in pediatric population in certain suspected patologies in the area of the PNS and nasal cavity.

Moreover, establishing PNS and nasal cavity volumetry as a standard part of the preoperative radiologic examination could contribute to safety and efficacy of the endoscopic sinus surgery and transnasal surgery of the skull base. The nasal cavity and PNS are very narrow spaces in which the orientation and manipulation with the endoscope and endoscopic tools can be quite demanding. Therefore, knowledge of the specific volumes of PNS might help deciding about indication of surgical route or approach.

Therefore, a user-friendly volumometric software compatible with the most common radiologic systems is needed – if applied in case of every patient examined by CT, enormous amounts of data could be obtained very quickly and easily interpreted and new norms of PNS volumes and their development in different populations could be established.

Conclusion

Results obtained by FOTOM^{08} Plus and especially the Fotom5 module are comparable to other volumometric tools (e.g. OssiriX) but since it is freeware, it is easily accessible and applicable in healthcare facilities all over the world, in contrast to other systems that are expensive and often tied to a specific platform, for example the currently available software Osirix.

Software can be widely used in otolaryngological practice. One of the possible usages is nasal cavity and PNS volume measurement. Knowledge of the PNS development, anatomy and volume is crucial for managing pathologies of this area.

The significance of the knowledge of the volume of PNS and the nasal cavity and their development lies in the great individual variability of the level of their pneumatization and actual size of the skull.

Moreover, establishing PNS and nasal cavity volumetry as a standard part of the preoperative radiologic examination could contribute to safety and efficacy of the endoscopic sinus surgery and transnasal surgery of the skull base. The nasal cavity and PNS are very narrow spaces in which the orientation and manipulation with the endoscope and endoscopic tools can be quite demanding.

Therefore, knowledge of the specific volumes of PNS might help deciding about indication of surgical route or approach.

The developed software can be easily used to measure PNS volumes even by non-medical professionals. Large amounts of data can be obtained very quickly and easily interpreted and new norms of PNS volumes and their development in different populations can be established.

Acknowledgements

The paper has been partially supported by Grant of SGS No. SP2022/22 and also has been completed thanks to the financial support provided to VSB-Technical University of Ostrava by the Czech Ministry of Education, Youth and Sports from the budget for conceptual development of science, research and innovations for the 2022 year.

This article is presented at the 30th International Conference with International Participation "Telecom 2022", 27–28 October 2022, Sofia, Bulgaria.

REFERENCES

[1] Lafci Fahrioglu S., Andaloro C.: STATPEARLS [Internet]. StatPearls Publishing; Treasure Island (FL): Nov 14, 2018. Anatomy, Head and Neck, Sinus Function and Development.

[2] Cappello Z.J., Dublin A.B. Anatomy, Head and Neck, Nose Paranasal Sinuses. [Updated 2018 Oct 27]. In: StatPearls [Internet]. Treasure Island (FL): StatPearls Publishing; 2019 Jan.

[3] Arslan H., Aydinlioglu A., Bozkurta M., Egelic E. Anatomic variations of the paranasal sinuses: CT examination for endoscopic sinus surgery. Auris Nasus Larynx, Jan 1999, 26 (1): 39-48.

[4] Sederberg, T. BYU Bézier curves,

http://www.tsplines.com/resources/class_notes/Bezier_curves.pdf

[5] Ličev L. FOTOMNG¨system, system, architecture, functions and usage. Praha, Publishing BEN Praha a.s., 2015.

[6] Sojka E. Digital image processing and analysis, Ostrava, Publishing VŠB-TU Ostrava, 2000.

[7] Chan T.F., Vese L.A. Active Contours without Edges. IEEE Trans. on Image Proces., vol 10, 2001.

[8] Li C., Kao C.Y., Gore J.C., Ding Z. Minimization of Region-Scalable Fitting Energy for Image Segmentation, IEEE Transactions on Image Processing [online], vol. 17(10), 2008.

[9] Cruz-Aceves I. et al. Multiple active contours guided by differential evolution for medical image segmentation, Computational and mathematical methods in medicine, 2013.

[10] Georgieva V. Homomorphic filtering approach for narrow band images enhancement, Journal of Applied Electromagnetism, Vol.17/2, 13-22, 2015.

[11] Callahan S.P., Callahan J.H., Sheidegger C.E., Cláudio T. Direct Volume Rendering: A 3D Plotting Technique for Scientific Data, 2007, http://www.sci.utah.edu/~cscheid/pubs/ dvr.pdf

[12] Kobližková P., Plášek M., Čábalová L., Mičaník J., Komínek P., Matoušek P. Development of maxillary sinuses and ethmoid cells in children according to computed tomography – a volumometric study. Otorinolaryngologie a Foniatrie, 2019, 3 (68): 131-134.

[13] Hybášek I. Propedeutics in Otorhinolaryngology. First edition. Praha, Galén, 1999: 17-18.

[14] Kawarai Y., Fukushima K., Ogawa T. et al. Volume quantification of healthy paranasal cavity by three-dimensional CT imaging. Acta Otolaryngol Suppl, 1991, 540: 45-49.

[15] Wolf G., Anderhuber W., Kuhn F. Development of the paranasal sinuses in children: implications for paranasal

sinus surgery. Ann Otol Rhinol Laryngol, 1993, 102(9): 705-711.

[16] Cohen O., Warman M., Fried M. et al. Volumetric analysis of the maxillary, sphenoid and frontal sinuses: A comparative computerized tomography based study. Auris Nasus Larynx. 45, 2018, 1: 96-102.

[17] Masri A. A., Yusof A., Hassan R. A three dimensional computed tomography (3D-CT): a study of maxillary sinus in malays. CJBAS. September, 1, 2013, 2: 125-134.

[18] Popov G. Use of system diversity as tool for identification, 2018 International Conference on High Technology for Sustainable Development, DOI: 10.1109/HiTech45121.2018, Publisher: IEEE

Lachezar Lichev - *VŠB-TU Ostrava, Department of Computer Science, Faculty of Electrical Engineering and Computer Science, 708 33 Ostrava-Poruba, Czech Republic 17, Listopadu 15,*

e-mail: lacezar.licev@vsb.cz

Viktória Hránková, Michaela Masárová, Jakub Lubojacký, Petr Matoušek - *University Hospital Ostrava, Department of Otorhinolaryngology and Head and Neck Surgery, Department of Craniofacial Surgery, Faculty of Medicine, (Head of Department prof. P. Komínek, MD, PhD, MBA),*

e-mails: viktoria.hrankova@fno.cz,
michaela.masarova@fno.cz,
jakub.lubojacky@fno.cz,
petr.matousek@fno.cz

Received on: 27.10.2022

How robust is the United Kingdom justice system against the advance of deepfake audio and video?

Dr Karl O. Jones, Bethan S. Jones

A recent development is the application of AI to either alter or create video and audio files - called Deepfakes. The paper examines the issues arising from deepfakes, to determine how robust the UK justice system is against deepfakes. The work analyses deepfake technology, with respect to an evaluation of professional knowledge, evidential standards, and current legislation. The paper discusses difficulties presented by deepfakes, highlighting the need for methods to authenticate digital evidence, and considers what UK legal remedies can protect the justice system and public from digitally falsified evidence. The paper concludes with potential recommendations for the justice system.

Keywords – Audio Forensics, Deepfake, Law, Video Forensics.

1. Introduction

The aim of this work was to determine the robustness of the United Kingdom (UK) justice system against the advances of deepfake audio and video technology [1], by evaluating how equipped the justice system is in handling this new technology.

Deepfakes are defined as 'artificial intelligence or machine-learning applications that merge, combine, replace and superimpose images and video clips onto a video, creating a fake video that appears authentic' [2]. Arguably, knowledge of deepfakes is incredibly uncommon in the justice system; many individuals, government agencies and policy makers misunderstand their importance and possible impact [3], especially regarding the risks they pose to legal and regulatory systems. Remarkably, a lack of findings in legislation, establishes that legal professionals are unable to protect the public from deepfake technology. Furthermore, it is worthy to note there is a lack of standards and processes governing deepfakes and their presence within the justice system [4]. Worryingly, other legal jurisdictions have a wider grasp and knowledge of deepfakes and are therefore better prepared to handle their existence within the law [1]. Moreover, case law surrounding deepfakes is incredibly sparse with no evidentiary processes being displayed [5]. This paper explores the relationship between audio and video deepfakes, and evidential processes and procedures, resulting in an evaluation of UK Law, leading to suggestions for potential reforms. This area of research is highly significant within the UK justice system because deepfake technology can create serious doubts for the reliability of evidence [5], which creates serious concerns for miscarriages of justice and perverting the course of justice. The paper will deeply challenge the difficulties created by deepfake technology, along with scrutinizing English law to evaluate the difference in protection given to the public against the dangers of deepfake technology [1].

2. Audio and video deepfakes

In reality, there are numerous examples of deepfakes, many encompassing superimposed images and videos of celebrities [1]. However, the history of deepfakes can be split into two categories; fakes and deepfakes. This is because fakes are created by humans undertaking the work themselves, whereas deepfakes require deep learning processes [6] and are effectively creating something that has never been real [2]. One of the most prominent forms of deepfakes are those related to pornography.

Since deep learning processes focuses on the ability to learn from inputted data [7], it is understandable to see how deepfakes are so easily created, establishing their ever-growing presence in society. One approach to creating a deepfake video requires the developer to train a neural network with many hours of video footage of the person being 'faked' so that an understanding of what they look like and how they move is gained. Following this, the trained neural network works with computer generated graphics to superimpose the 'faked' person onto a different actor. Similarly, for audio, the neural network uses many hours of audio recordings to learn

the person's voice and inflections, such that it generates an audio file from a written script [7]. One notable deepfake is the video of footballer David Beckham apparently speaking several languages fluently for a "Malaria Must Die" advert [8], an image from the video is shown in Fig 1.

University of Washington researchers created a realistic version of President Barack Obama, including a precise model of how his mouth moves allowing them to make their deepfake Obama 'say' anything they wished [9]. Cybersecurity company Deeptrace™ estimates there were 14,698 deepfake videos online in 2019, up from 7,964 the previous year [10].

Fig. 1. David Beckham deepfake audio and video.

The complexity of deepfake technology [7] allows it to create faces of people that do not exist, such as that shown in Fig. 2. Without suitable procedures in place only obvious flaws in facial generation might be noticed giving a hint at a deepfake image.

Fig. 2 Two images from "thispersondoesnotexist.com".

A deepfake that has come to light recently is voice cloning [6]. In 2020, a Hong Kong bank manager received a telephone call from a man whose voice he recognized as company a director with whom he had spoken before. This company was about to make an acquisition, and hence required the bank to authorise a transfer of $35 million. Later, it was discovered that the bank manager had been deceived, where fraudsters had utilised deepfake technology to clone the director's voice [6].

Deepfakes have been presented to a UK court in the form of audio evidence. Byron James, a UK family lawyer, said, '*deepfake audio was used in a custody battle to try and portray a father as threatening*' [3]. Here the deepfake audio was created using freely available systems on the internet '*to create highly sophisticated and plausible fake footage*' [3].

3. Knowledge of justice system legal professionals

From the lack of information currently available [11], it is clear that many professionals within the UK justice system are unaware of deepfakes and their scope within society [3]. UK family lawyer Byron James argues, '*courts take evidence such as audio recordings, visual footage and written documents at face value*', when in reality courts should be sceptical, adding, '*the whole legal system needs to catch up, it's not good at technology, there are really easy ways to manipulate the system*' [3].

3.1. Police and forensic technicians

It is obvious that video and audio recordings are now an inherent part of everyday life and are key technologies for both the general public and the police service [12]. However, evidence showing police awareness of deepfakes is sparse, arguably suggesting that they are still unaware of deepfakes and associated malicious capabilities [12].

Similar to police officers, forensic technicians are also generally unaware of deepfake technology and its far-reaching capabilities [12]. This is illustrated through the expectations of the qualifications of audio/video forensic technicians, where many UK police forces do not require a degree qualification and frequently do not even expect proven knowledge of audio/video theory. Arguably, forensic technicians need to be fully aware of deepfake technology and its capabilities since audio/video evidence is widely used in criminal proceedings [13], which potentially might have been manipulated or faked.

3.2. Barristers & Lawyers

Having been convicted of murder from enhanced footage from a surveillance tape, Nooner [5] identifies how barristers are totally unaware of potential doctored evidence. It was stated that '*relevant computer-enhanced still prints made from videotape recordings are admissible in evidence when they are verified as reliable representations of images recorded on master videotapes*' [5]. No attempt was

made to verify the reliability of the evidence, including the original surveillance tape [5]. Although this case was in the mid-1990s, similar difficulties are still present, namely that technology is speeding ahead of the justice system, especially in relation to the knowledge of those employed [3]. The lawyer for a father in a child custody case, Byron James stated, '*this was the first instance in around 30 years of legal practice that he had seen such a case of 'deep faking"* [3]. This provides an insight into the lack of knowledge barristers have around deepfakes and their damaging capabilities [3]. However, James also stated, '*unless you're aware of the possibility of something being fake, it's difficult to know*', suggesting barristers should be more aware of deepfake or doctored evidence, to protect the UK justice system from being exploited.

3.3. Judges

One recent case that exemplifies the lack of knowledge judges have surrounding video technology is the Kyle Rittenhouse Trial in the USA [14]. During the trial, a video was zoomed into to see the specified image more clearly [14]. It was argued by Rittenhouse's lawyer that '*using an iPad to zoom in on a video should not be allowed because Apple's AI creates "what it thinks is there, not what necessarily is there"'* [14]. While this case is not about deepfake technology, arguably, most people are familiar with zooming on photographs taken on their mobile phones, thus having a judge not fully aware of what happens when a zoom is used is of some concern [3]. Arguably, legal professionals who understand AI and deep-learning processes [7], will be shocked to learn that the judge '*bought into that possibility and ruled that the jurors were only allowed to view the video in its original size*' [14]. This points towards the lack of knowledge judges have relating to the scope of deepfake technology [14].

4. Evidence in the UK Legal System

'*Evidence is the information with which the matters requiring proof in a trial are proved*' [15]. Munday [16] states, '*the evidence of a fact is that which tends to prove it… something that may satisfy an inquirer of the fact's existence*'. Arguably, in a court of law the principle of evidence is used to determine a belief in something [15], whether it be through physical or verbal evidence, such as blood evidence or witness testimony. Thus, the notion of evidence is an extremely important factor when discussing deepfakes, since it establishes the court's ability to not only detect but handle the possibility of both perverting the course of justice and miscarriages of justice through doctored evidence.

4.1. Audio and video evidence

Examples of audio evidence are ever-present within the justice system [17], whether it be audio on a tape recording, recorded phone conversations or audio obtained through recorded police interviews [18] Video evidence within the justice system is an ever-growing phenomenon, encapsulating different types of recordings such as from, CCTV, police body cameras, mobile phones, dash cameras and Ring™ doorbells, which might include audio [17]. The presence of such evidence throughout the justice system creates a variety of complex issues [19], highlighting the need for debate around court processes and procedures, and the awareness of legal professionals, of both handling and understanding the physics/technology of this type of evidence, e.g. how a camera lens might distort an image.

4.2. Deepfake evidence

All evidence, whether it be audio, video, blood, fingerprints etc must be handled correctly to avoid corruption [4], as Horsman and Sunde [20] state '*evidence must be reliable if it is to be used as part of any legal decision making*'. Camacho *et al.* [21] state '*an audio recording can be used as evidence in a legal process only if the integrity of the recording is demonstrated… the file has not been manipulated either by the victim, the suspect or by a third part*'. This demonstrates the lack of knowledge and understanding within the justice system relating to possible deepfake evidence since currently, there are no identifiable practices defined either by custom or statute to handle this type of evidence. For example, if the evidence introduced into court was already manipulated prior to seizure by the police [21], this creates serious concerns regarding the fairness of the law [3].

4.3. Audio and video forensics

The British Standards Institute [4] assert '*an organisation should adopt policies and plans to assure the preservation of digital evidence and… the organisation should maintain processes that assure the integrity of investigations, the independence of experts, and the evidential value of binary information*'. Therefore, it is quite worrying to note that police forces have no processes or procedures in place to establish, maintain or preserve the integrity of digital evidence [22]. The case of Victoria Breeden [17] demonstrates how law authorities are blind to the

ever-growing phenomenon of potential deepfake digital evidence [17]. This case involved a recording of Breeden stating '*how easy would it be to make someone disappear*' [17], regarding hiring a hitman to kill her ex-husband. The police took the recording at face value, carrying out no work to determine the authenticity of the recording since it was made by a third party.

This situation creates a serious problem within the justice system, because not only are legal professionals not looking for manipulated evidence, even if they were, they may not notice [4]. As Lv *et al.* state [23], '*digital audio recording is much convenient nowadays… even non-professionals can modify audio without leaving any visible traces*', for example the free software Audacity (audacityteam.org), is simple to use whilst having powerful audio editing/mixing facilities.

5. UK Legislation

Although legal professionals are aware of fabricated evidence, such as creating fake wills for financial gain, the same individuals have little knowledge of the endless possibilities of deepfake evidence and their impact [3]. One piece of legislation that highlights the issues with deepfake evidence is the Defamation Act 2013 [24]. Section 2, subsection 1 states that '*it is a defence to an action for defamation for the defendant to show that the imputation conveyed by the statement complained of is substantially true*'. If the statement made was manufactured using deepfake technology, the truthfulness of the statement cannot be refuted, since there is no evidence to prove otherwise.

Pavis [25] states, '*the UK is a jurisdiction ripe for reform on the issue of deepfakes as the government is undertaking a series of reviews in connected areas of law*'. Furthermore, '*surprisingly little has been written on deepfakes in relation to UK law*' [25]. Pavis continues, arguing, '*there are significant differences in the legal provisions applicable to Deepfakes between national laws*' [25], indicating that the UK justice system is ill-equipped to handle the advance of deepfake technology, with little to no legislation available to eradicate this digital crime [25].

The Law Commission (TLC) stated that '*as part of its efforts to make the UK the safest place online in the world… the Law Commission was to review the current law around abusive and offensive online communications and highlight any gaps*' [26], as well as reviewing the law on '*online sexual abuse or image-based abuse which included deepfakes*' [25]. However, '*by contrast, Deepfakes were left out of the scope of a subsequent government review assessing the need to reform the UK intellectual property framework in light of AI technology*' [25]. Controversially, TLC did not provide any guidance in tackling deepfake technology [26]. Although there has been acknowledgement of the issues of deepfake technologies within TLC [25], they have not been acted upon.

Instead of reviewing the law once it has been made, contestably, law makers should enable processes to look for deepfakes first, thus eliminating the need for such reviews to take place [25]. This can be done by conducting an investigation into '*how effectively the criminal law protects personal privacy online*' [26], since deepfakes are '*a growing concern in both politics and personal life*' [27].

5.1. Illustrative example of problem with current UK legislation

While there is no current legislation governing deepfakes [26], existing laws should be kept up to date and fit-for-purpose. The Protection of Children Act 1978 [28], is '*an Act to prevent the exploitation of children by making indecent photographs of them; and to penalise the distribution, showing and advertisement of such indecent photographs*'. Section 7, sub-section 7 states that a '*pseudo-photograph means an image, whether made by computer-graphics or otherwise howsoever, which appears to be a photograph*'. Furthermore, sub-section 6 identifies that a "child" is '*a person under the age of 18*'. While the term 'pseudo-photograph' accepts an image can be computer generated, debatably, the definition of a 'child' under the Act [28] is a largely contentious issue. If an image has been created through deepfake technology, the individual in the photograph, arguably, does not exist. It is therefore necessary to put forward an argument of whether the image truly depicts a real 'person'. Arguably, the definition of a 'person' is highly subjective, dependent on personal interpretation. Some may only identify a 'person' as anyone with a heartbeat, while others can assume someone is a 'person' simply by viewing an image. Thus, current legislation should keep up to date with new technologies, since if the image was first established to be real or fake, resources, time and money would be spared. Another issue is shown in the wording of section 7, sub-section 7, where the Act relates to a type of image, '*which appears to be a photograph*' [28]. The term '*appears*' creates serious concern, as to be shown as reliable within a court of law, evidence must be authenticated [15]; appearing as something should not be an indication of

trustworthiness, especially regarding the ease with which deepfakes are currently being created [29]. Arguably, 'seeing is believing; people tend to accept images 'at face value'' [2]. Due to the probative value attached to images at trial, '*a photograph passes for incontrovertible proof that a given thing happened*' [30], leading people to be susceptible of being misled, because they will be convinced, regardless of whether the videos and images might have been fabricated' [2].

5.2. Improvements

Discussing the need for reform, Hany Farid, Professor at University of California, argues deepfakes are a '*technology that is easily weaponized*' [27], with Siwei Lyu, Professor at University of Albany, adding that deepfakes are a '*problem that isn't going to go away*' [27].

Albert Cahn, Executive Director of the Surveillance Technology Oversight Project, argues, '*laws must be updated to protect against clear cases of digital harassment… but government entities must avoid legislating for or against specific features because the technology is evolving rapidly*' [27]. However, David Greene, notes, '*if a deepfake is used for criminal purposes, then criminal laws will apply. There is no need to make new, specific laws about deepfakes*' [27], suggesting new laws are not essential, rebutting the argument that any improvements are required at all [27].

5.3. Comparison

There is a significant lack of legislation within England and Wales governing deepfake technology [1]. However, it is interesting to note that Scottish Law differs slightly in its response criminalising '*non-consensual disclosure of intimate photographs and films, with both 'photograph' and 'film' defined to include 'whether or not the image has been altered in any way'*' [31]. While it could be argued that Scottish Law targets pornographic manipulated content more specifically [31], other jurisdictions specifically seek out deepfakes [1]. Greengard [27] argues that '*not surprisingly, deepfakes are also testing the legal system and prompting the U.S. Congress, States, and other entities to take action*' [27]. An example of this can be shown quite recently, in September 2019 [1], when '*Texas law… criminalised the creation of a 'deep fake video' and causing it to be published or distributed within 30 days of an election, with intent to injure a candidate or influence an election result*' [1]. Furthermore, the proposed US Malicious Deep Fake Prohibition Act of 2018 '*would introduce penalties for those who create, with intent to distribute, fake videos that facilitate criminal or tortious conduct*' [27].

6. Recommendations for improvement

Clearly, the lack of law and the problems existing with current legislation created by deepfake technology plainly shows the need for reform [28]. While deepfakes have been in existence for some years, within the justice system they are in their infancy but are beginning to concern legal scholars. Instead of actually targeting the issue head on to eradicate their use within the courtroom [29], effort has been directed at '*how to prevent, mitigate, and punish the abuse of deepfake technology for harmful purposes*' [29].

6.1. Lack of professional knowledge

Pfefferkorn argues '*deepfakes will soon make trial attorneys' and judges' jobs more difficult… they will complicate normal trial proceedings and may give courts reason to revisit the continued adequacy of current rules and standards governing digital evidence*' [29]. Thus, it is imperative that legal professionals become educated about the ever-growing presence deepfakes in the courtroom. Ideally this education should be provided by specialists in audio/video technology, and by specialists in artificial intelligence.

Additionally, forensic technicians must also be trained in correct processing of audio/video evidence in general, as well as in methods for attempting to identify deepfake material.

Furthermore, UK police require training in their approach to seizing audio/video material for evidential purposes, for example currently the technical specifications of video cameras or audio recording devices are not required to be documented, thus making appropriate forensic processing of the material problematic.

6.2. Standards, processes and procedures

Pfefferkorn suggested '*if proving which videos are fake becomes too difficult, then maybe it would be easier to establish which videos aren't…to prove an affirmative rather than a negative*' [29]. However, the same problems would still arise, if no processes and standards exist, there is no way to authenticate evidence [1]. Furthermore, the sophistication of deepfake systems will continue to advance making it harder for people to tell real from fake.

Although the UK justice system has standards and processes regarding the reliability of evidence

[32][33], debatably there is an apparent absence of standards and processes addressing deepfake technology [1]. In contrast, standards and processes surrounding deepfakes exist within different legal systems [1]. In detecting deepfakes, '*the U.S. government, academia, nonprofits, and the tech industry have all launched initiatives…to push forward the state of technology for detecting deepfakes*' [29]. Clearly similar initiatives are required for the UK justice system.

6.3. Legislation

Worryingly, if reforms are not taken seriously by legal professionals and policy makers, then there will be severe ramifications from the existence of evidence created/modified through deepfake within the justice system. The challenge of tackling the reliability of digital evidence within the courtroom is an epidemic the UK justice system is ill-equipped to handle [1], something that will only get worse if reforms are not made promptly throughout the judicial system.

7. Closing comments

It is clear to see that the UK justice system is wholly unaware and oblivious to the ever-growing presence of audio/video deepfake technology [1]. The paper has identified that there is a significant absence of legal professional knowledge relating to deepfake technology and its capabilities [3]. This obviously creates a concern regarding the operational procedures of the courtroom [29], since '*lawyers will have to exercise greater diligence in verifying the authenticity of video evidence…that includes learning the signs of a deepfake*' [29]. Furthermore, the paper clearly illustrates that there are no existing evidential standards, processes or procedures to either handle or detect deepfake material [11][33]. Logically then, the justice system cannot be shown to be robust against the advance of deepfake technology.

Debatably, the UK justice system does not have the necessary capacity to put forward the required processes and standards to tackle deepfake technology, because no knowledge has been gained [1]. Furthermore, the deficiency of law around deepfakes attests to the argument that the UK justice system is ill-equipped and unable to cope [29]. Pfefferkorn questions, '*when deepfakes cause harm - whether on a small scale… or large scale, how should the law respond? What existing civil and criminal laws could be invoked to redress those harms?... and what new regulations may be called for?*' [29]. Perhaps it is the case that deepfakes are such an exclusive and unknown marvel that the law will never be able to catch up [29].

However, it is reasonable to suggest that the UK justice system could be identified as robust against deepfake audio and video technology if professional knowledge is improved, new law is brought into force and evidential processes, standards and procedures were developed [29]. Pfefferkorn claims '*with thoughtful advance preparation, trial lawyers and judges will be equipped to handle this new challenge*' [29].

Thus, there is an urgent need for the UK Ministry of Justice, as the lead organisation within the justice system, to begin a process of informing people across the justice system about the existence of deepfakes. This is just an initial step, with a need for further intervention in the form of formal education about deepfake creation and its possible impact on evidence, along with the introduction of processes and procedures to ensure that every effort is made to determine if any audio or video evidence has been subject to any form of deepfake technology. It should be noted that certain proof that audio/video evidence is not deepfake might not be possible, however that should not prevent examination to determine if there is an indication of deepfake material.

This article is presented at the 36th International Conference on Information Technologies (InfoTech-2022), IEEE Conference, Rec. # 55606, September 15-16, 2022, Bulgaria.

REFERENCES

[1] Che Ekaratne, S. (2020) Manipulated images: a taxonomy. European Intellectual Property Rights, Vol. 42(6), pp. 353-363.

[2] Maras, M-H. and Alexandrou, A. (2019). Determining authenticity of video evidence in the age of artificial intelligence and in the wake of Deepfake videos. International Journal of Evidence & Proof, Vol. 23 (3), pp. 255-262

[3] The Telegraph. (2020). 'Doctored audio evidence used to damn father in custody battle' www.telegraph.co.uk/news/2020/01/31/deepfake-audio-used-custody-battle-lawyer-reveals-doctored-evidence.

[4] British Standard Institution. (2016). Information Technology: Governance of digital forensic risk framework. Standards Publication BS EN ISO/IEC 30121:2016.

[5] Nooner v State of Arkansas (1995) 907 S.W.2d 677

[6] Cornell University. (2014). Generative Adversarial Networks. arxiv.org/abs/1406.2661.

[7] IBM. (2020). Deep Learning. (2020) www.ibm.com/cloud/learn/deep-learning.

[8] www.youtube.com/watch?v=QiiSAvKJIHo

[9] Suwajanakorn, S., Seitz, S.M. and Kemelmacher-Shlizerman, I, (2017). Synthesizing Obama: Learning Lip Sync from Audio. University of Washington.

[10] DeGeurin, M. (2021). Kyle Rittenhouse's Lawyers Claim Zooming-In on an iPad Fundamentally Alters a Digital Image. gizmodo.com/kyle-rittenhouse-s-lawyers-claim-zooming-in-on-an-ipad-1848040149.

[11] Forensic Science Regulator, (2020). Codes of Practice and Conduct. 2 FSR-C-119 pp. 1-35

[12] MacLennan-Brown, K. and Cohen, N. (2020). Digital Imaging and Multimedia Procedure. Defence Science and Technology Laboratory, Vol. 3, pp. 1-45.

[13] The CCTV User Group. (2022). Concerns about how police process CCTV images for the courts. www.cctvusergroup.com/post/concerns-about-the-processing-of-cctv-images-for-the-courts-by-the-police.

[14] Palmer, S. (2021). 'Kyle Rittenhouse's Lawyers Point Out the Obvious' www.shellypalmer.com/2021/11/kyle-rittenhouses-lawyers-point-out-the-obvious.

[15] Choo A, Evidence (2018) 5th edn, Oxford University Press.

[16] Munday, R. (2018). Cross and Tapper on Evidence. 13th edn, Oxford University Press.

[17] BBC News (2022) 'Victoria Breeden jailed for trying to get ex-husband murdered' www.bbc.co.uk/news/uk-england-cambridgeshire-53612107.

[18] Maher, R.C. (2018). Principles of Forensic Audio Analysis. Springer International Publishing

[19] Pattenden, R. (2008). Authenticating "things" in English law: principles for adducing tangible evidence in common law jury trials. International Journal of Evidence & Proof, Vol. 12(4), pp. 273-302

[20] Horsman, G. and Sunde, N. (2020). Part 1: The need for peer review in digital forensics. Forensic Science International: Digital Investigation. Vol. 35.

[21] Camacho, S., Ballesteros, D.M and Renza, D. (2019) A cloud-oriented integrity verification system for audio forensics. Computers and Electrical Engineering, Vol. 73, pp. 259-267

[22] Tully, G. (2021). Forensic Science Regulator Annual Report 2020.

[23] Lv, Z., Hu, Y., Li, C-T. and Liu, B-B. (2013). Audio forensic authentication based on MOCC between ENF and reference signals. IEEE China Summit and International Conference on Signal and Information Processing. pp. 427-431.

[24] Defamation Act 2013. (2013). www.legislation.gov.uk/asp/2013/26/contents

[25] Pavis, M. (2021). Rebalancing our regulatory response to Deepfakes with performers' rights. Convergence: The International Journal of Research into New Media Technologies, Vol. 27(4), pp. 974-998.

[26] Law Commission (2018). Abusive and Offensive Online Communications.

[27] Greengard, S. (2020). Will Deepfakes Do Deep Damage? Communications of the Association for Computing Machinery, Vol. 63 (1), pp. 1.

[28] [28] Protection of Children Act 1978. (1978). legislation.gov.uk/ukpga/1978/37/contents.

[29] [29] Pfefferkorn, R. (2009). "Deepfakes" In The Courtroom. Public Interest Law Journal, Vol. 29, pp. 246-276

[30] Sontag, S. (1977). In Plato's Cave on Photography. Delta Books, USA.

[31] Abusive Behaviour and Sexual Harm Act (Scotland) 2016. (2016). legislation.gov.uk/asp/2016/22/contents.

[32] Criminal Justice Act 2003. (2003). www.legislation.gov.uk/ukpga/2003/44/contents.

[33] Police and Criminal Evidence Act 1984. (1984). legislation.gov.uk/ukpga/1984/60/contents.

Dr Karl O. Jones *- School of Engineering, Liverpool John Moores University, Liverpool, United Kingdom. Karl completed his BEng in Electrical and Electronic Engineering at Liverpool Polytechnic, and his PhD at Liverpool John Moores University. His research interests are Evolutionary Computation, Artificial Intelligence, Control Engineering and Audio/Video Forensics.*

Tel: +44 (0) 151 231 2199 e-mail: K.O.Jones@ljmu.ac.uk

Bethan S. Jones - *Law School, University of Cumbria, Carlisle, Cumbria, United Kingdom. Bethan completed her LLB in Law at the University of Cumbria in 2022, and started her PhD in the robustness of the UK Justice System to Advances in Audio/Video Forensic Technology.*

e-mail: B.S.Jones@2022.ljmu.ac.uk

Received on: 24.10.2022

ЕЛЕКТРОТЕХНИКА И ЕЛЕКТРОНИКА Е+Е

57 год. 9-12/2022

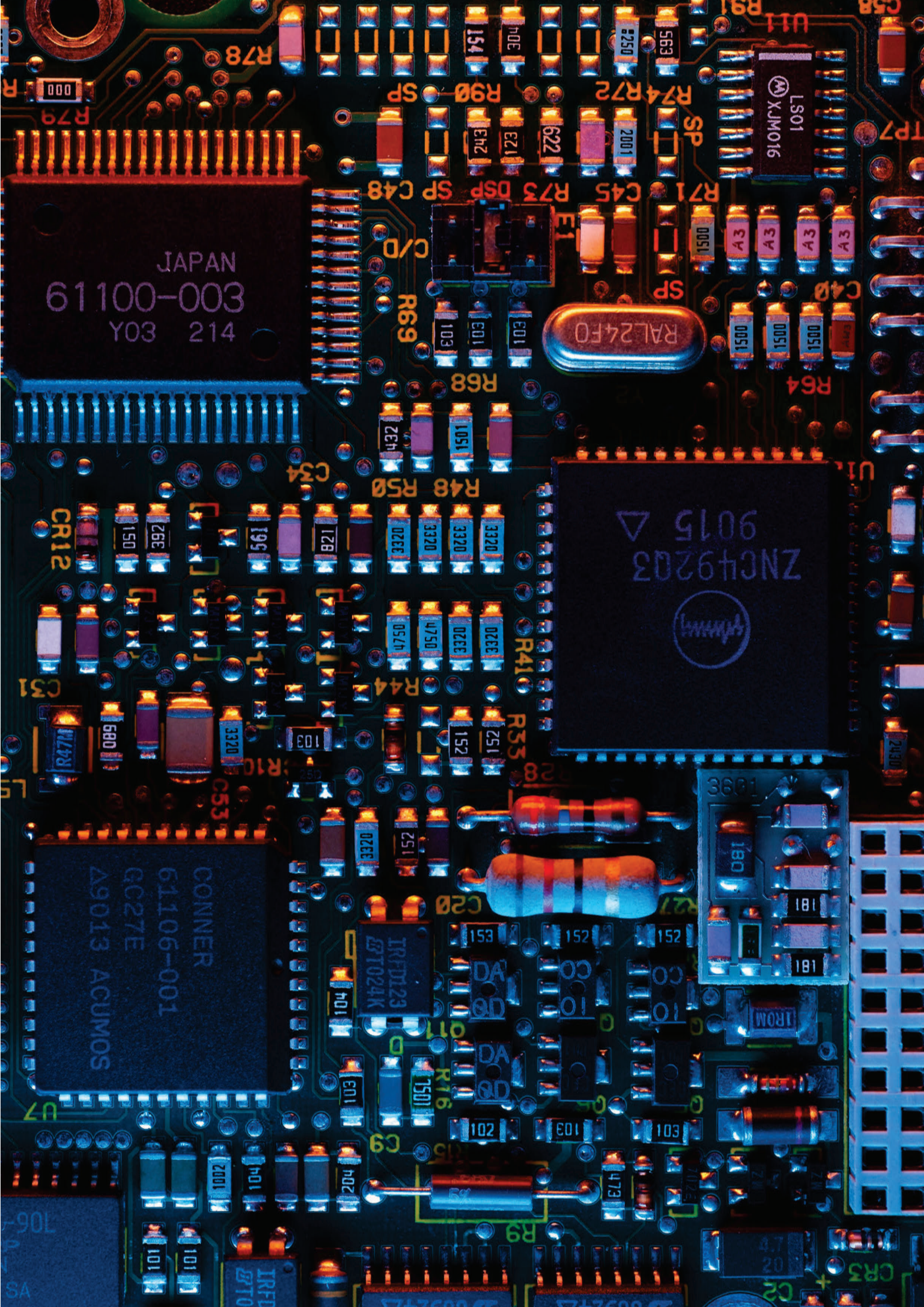
Научно-техническо списание

Издание на: **Съюза по електроника, електротехника и съобщения /CEEC/**

Адрес:
ул. “Раковски” № 108
ет. 5, стая 506
София 1000
тел.: +359 2 987 97 67
e-mail: epluse@ceec.bg
http://epluse.ceec.bg

ISSN 0861-4717 Print
eISSN 2603-5421 Online

С Ъ Д Ъ Р Ж А Н И Е


JAPAN
61100-003
Y03 214
CONNER
61106-001
GC27E
Δ9013 ACUMOS