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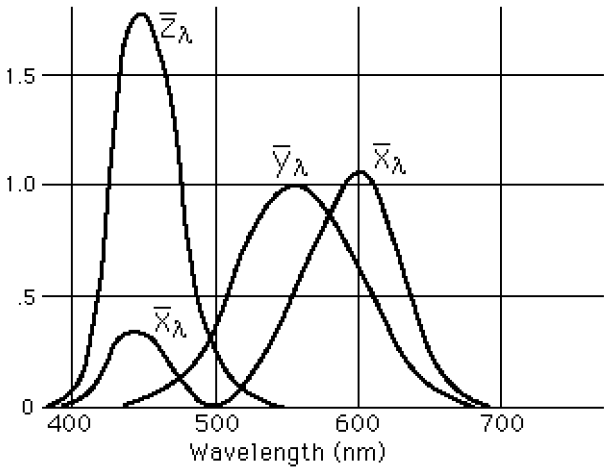
CIE XYZ

Spis treści

1. CIE XYZ

Trójchromatyczny model barw CIE XYZ został opracowany w 1931 roku przez Międzynarodową Komisję Oświetleniową CIE i stanowi rozwinięcie układu CIE RGB. System CIE XYZ wykorzystuje trzy fikcyjne barwy podstawowe x, y i z, otrzymane przez przekształcenie składowych widmowe $\bar{x}_\lambda$, $\bar{y}_\lambda$ i $\bar{z}_\lambda$, które są nieujemne na całym zakresie fal. Składowa y zawiera informację o strumieniu światła, a składowe x i z zawierają wyłącznie informację o barwie.

Rysunek 1 przedstawia wykres zależności wartości składowych trójchromatycznych CIE XYZ (krzywe $\bar{x}_\lambda$, $\bar{y}_\lambda$, $\bar{z}_\lambda$) od długości fali.



Rysunek 1. Składowe trójchromatyczne CIE XYZ

System CIE XYZ został zdefiniowany dla normalnego obserwatora CIE 1931 (kąt obserwacji 2°) i jest zalecany do używania przy polach widzenia nie przekraczających w świetle dziennym 4°.

1.1. Współrzędne trójchromatyczne

Podobnie jak w przypadku systemu CIE RGB określone zostały współrzędne trójchromatyczne w trójwymiarowej przestrzeni XYZ. Analogicznie płaszczyzna barw ma równanie $x + y + z = 1$. Poszczególne wartości współrzędnych trójchromatycznych x_λ, y_λ i z_λ wyznaczane są z następujących zależności:

$$x_\lambda = \frac{\bar{z}_\lambda}{\bar{x}_\lambda + \bar{y}_\lambda + \bar{z}_\lambda}$$

$$y_\lambda = \frac{\bar{y}_\lambda}{\bar{x}_\lambda + \bar{y}_\lambda + \bar{z}_\lambda}$$

$$z_\lambda = \frac{\bar{z}_\lambda}{\bar{x}_\lambda + \bar{y}_\lambda + \bar{z}_\lambda}$$

Oczywiście dla tak zdefiniowanych współrzędnych trójchromatycznych zachodzi równość:

$$x_\lambda + x_\lambda + x_\lambda = 1$$

Tabela 1 zawiera zestawienie wartości składowych trójchromatycznych widmowych, a tabela 2 współrzędnych trójchromatycznych w układzie CIE XYZ dla fal o długości co 5 nm.

λ [nm]	$\bar{x}_\lambda$	$\bar{y}_\lambda$	$\bar{z}_\lambda$
360	0,000129900000	0,000003917000	0,000606100000
365	0,000232100000	0,000006965000	0,001086000000
370	0,000414900000	0,000012390000	0,001946000000
375	0,000741600000	0,000022020000	0,003486000000
380	0,001368000000	0,000039000000	0,006450001000
385	0,002236000000	0,000064000000	0,010549990000
390	0,004243000000	0,000120000000	0,020050010000
395	0,007650000000	0,000217000000	0,036210000000
400	0,014310000000	0,000396000000	0,067850010000
405	0,023190000000	0,000640000000	0,110200000000
410	0,043510000000	0,001210000000	0,207400000000
415	0,077630000000	0,002180000000	0,371300000000
420	0,134380000000	0,004000000000	0,645600000000
425	0,214770000000	0,007300000000	1,039050100000
430	0,283900000000	0,011600000000	1,385600000000
435	0,328500000000	0,016840000000	1,622960000000
440	0,348280000000	0,023000000000	1,747060000000
445	0,348060000000	0,029800000000	1,782600000000
450	0,336200000000	0,038000000000	1,772110000000
455	0,318700000000	0,048000000000	1,744100000000
460	0,290800000000	0,060000000000	1,669200000000
465	0,251100000000	0,073900000000	1,528100000000
470	0,195360000000	0,090980000000	1,287640000000
475	0,142100000000	0,112600000000	1,041900000000
480	0,095640000000	0,139020000000	0,812950100000
485	0,057950010000	0,169300000000	0,616200000000
490	0,032010000000	0,208020000000	0,465180000000
495	0,014700000000	0,258600000000	0,353300000000
500	0,004900000000	0,323000000000	0,272000000000
505	0,002400000000	0,407300000000	0,212300000000
510	0,009300000000	0,503000000000	0,158200000000

λ [nm]	$\bar{x}_\lambda$	$\bar{y}_\lambda$	$\bar{z}_\lambda$
515	0,029100000000	0,608200000000	0,111700000000
520	0,063270000000	0,710000000000	0,078249990000
525	0,109600000000	0,793200000000	0,057250010000
530	0,165500000000	0,862000000000	0,042160000000
535	0,225749900000	0,914850100000	0,029840000000
540	0,290400000000	0,954000000000	0,020300000000
545	0,359700000000	0,980300000000	0,013400000000
550	0,433449900000	0,994950100000	0,008749999000
555	0,512050100000	1,000000000000	0,005749999000
560	0,594500000000	0,995000000000	0,003900000000
565	0,678400000000	0,978600000000	0,002749999000
570	0,762100000000	0,952000000000	0,002100000000
575	0,842500000000	0,915400000000	0,001800000000
580	0,916300000000	0,870000000000	0,001650001000
585	0,978600000000	0,816300000000	0,001400000000
590	1,026300000000	0,757000000000	0,001100000000
595	1,056700000000	0,694900000000	0,001000000000
600	1,062200000000	0,631000000000	0,000800000000
605	1,045600000000	0,566800000000	0,000600000000
610	1,002600000000	0,503000000000	0,000340000000
615	0,938400000000	0,441200000000	0,000240000000
620	0,854449900000	0,381000000000	0,000190000000
625	0,751400000000	0,321000000000	0,000100000000
630	0,642400000000	0,265000000000	0,000049999990
635	0,541900000000	0,217000000000	0,000030000000
640	0,447900000000	0,175000000000	0,000020000000
645	0,360800000000	0,138200000000	0,000010000000
650	0,283500000000	0,107000000000	0,000000000000
655	0,218700000000	0,081600000000	0,000000000000
660	0,164900000000	0,061000000000	0,000000000000
665	0,121200000000	0,044580000000	0,000000000000
670	0,087400000000	0,032000000000	0,000000000000
675	0,063600000000	0,023200000000	0,000000000000
680	0,046770000000	0,017000000000	0,000000000000
685	0,032900000000	0,011920000000	0,000000000000
690	0,022700000000	0,008210000000	0,000000000000
695	0,015840000000	0,005723000000	0,000000000000
700	0,011359160000	0,004102000000	0,000000000000
705	0,008110916000	0,002929000000	0,000000000000
710	0,005790346000	0,002091000000	0,000000000000
715	0,004106457000	0,001484000000	0,000000000000

λ [nm]	$\bar{x}_\lambda$	$\bar{y}_\lambda$	$\bar{z}_\lambda$
720	0,002899327000	0,001047000000	0,000000000000
725	0,002049190000	0,000740000000	0,000000000000
730	0,001439971000	0,000520000000	0,000000000000
735	0,000999949300	0,000361100000	0,000000000000
740	0,000690078600	0,000249200000	0,000000000000
745	0,000476021300	0,000171900000	0,000000000000
750	0,000332301100	0,000120000000	0,000000000000
755	0,000234826100	0,000084800000	0,000000000000
760	0,000166150500	0,000060000000	0,000000000000
765	0,000117413000	0,000042400000	0,000000000000
770	0,000083075270	0,000030000000	0,000000000000
775	0,000058706520	0,000021200000	0,000000000000
780	0,000041509940	0,000014990000	0,000000000000
785	0,000029353260	0,000010600000	0,000000000000
790	0,000020673830	0,000007465700	0,000000000000
795	0,000014559770	0,000005257800	0,000000000000
800	0,000010253980	0,000003702900	0,000000000000
805	0,000007221456	0,000002607800	0,000000000000
810	0,000005085868	0,000001836600	0,000000000000
815	0,000003581652	0,000001293400	0,000000000000
820	0,000002522525	0,000000910930	0,000000000000
825	0,000001776509	0,000000641530	0,000000000000
830	0,000001251141	0,000000451810	0,000000000000

Tabela 1: Składowe widmowe CIE XYZ 1931

λ [nm]	x_λ	y_λ	z_λ
360	0,175560	0,005294	0,819146
365	0,175161	0,005256	0,819582
370	0,174821	0,005221	0,819959
375	0,174510	0,005182	0,820309
380	0,174112	0,004964	0,820924
385	0,174008	0,004981	0,821012
390	0,173801	0,004915	0,821284
395	0,173560	0,004923	0,821517
400	0,173337	0,004797	0,821866
405	0,173021	0,004775	0,822204
410	0,172577	0,004799	0,822624
415	0,172087	0,004833	0,823081
420	0,171407	0,005102	0,823490

λ [nm]	x_λ	y_λ	z_λ
425	0,170301	0,005789	0,823911
430	0,168878	0,006900	0,824222
435	0,166895	0,008556	0,824549
440	0,164412	0,010858	0,824731
445	0,161105	0,013793	0,825102
450	0,156641	0,017705	0,825654
455	0,150985	0,022740	0,826274
460	0,143960	0,029703	0,826337
465	0,135503	0,039879	0,824618
470	0,124118	0,057803	0,818079
475	0,109594	0,086843	0,803563
480	0,091294	0,132702	0,776004
485	0,068706	0,200723	0,730571
490	0,045391	0,294976	0,659633
495	0,023460	0,412703	0,563837
500	0,008168	0,538423	0,453409
505	0,003859	0,654823	0,341318
510	0,013870	0,750186	0,235943
515	0,038852	0,812016	0,149132
520	0,074302	0,833803	0,091894
525	0,114161	0,826207	0,059632
530	0,154722	0,805864	0,039414
535	0,192876	0,781629	0,025495
540	0,229620	0,754329	0,016051
545	0,265775	0,724324	0,009901
550	0,301604	0,692308	0,006088
555	0,337363	0,658848	0,003788
560	0,373102	0,624451	0,002448
565	0,408736	0,589607	0,001657
570	0,444062	0,554714	0,001224
575	0,478775	0,520202	0,001023
580	0,512486	0,486591	0,000923
585	0,544787	0,454434	0,000779
590	0,575151	0,424232	0,000616
595	0,602933	0,396497	0,000571
600	0,627037	0,372491	0,000472
605	0,648233	0,351395	0,000372
610	0,665764	0,334011	0,000226
615	0,680079	0,319747	0,000174
620	0,691504	0,308342	0,000154
625	0,700606	0,299301	0,000093

λ [nm]	x_λ	y_λ	z_λ
630	0,707918	0,292027	0,000055
635	0,714032	0,285929	0,000040
640	0,719033	0,280935	0,000032
645	0,723032	0,276948	0,000020
650	0,725992	0,274008	0,000000
655	0,728272	0,271728	0,000000
660	0,729969	0,270031	0,000000
665	0,731089	0,268911	0,000000
670	0,731993	0,268007	0,000000
675	0,732719	0,267281	0,000000
680	0,733417	0,266583	0,000000
685	0,734047	0,265953	0,000000
690	0,734390	0,265610	0,000000
695	0,734592	0,265408	0,000000
700	0,734690	0,265310	0,000000
705	0,734690	0,265310	0,000000
710	0,734690	0,265310	0,000000
715	0,734548	0,265452	0,000000
720	0,734690	0,265310	0,000000
725	0,734690	0,265310	0,000000
730	0,734690	0,265310	0,000000
735	0,734690	0,265310	0,000000
740	0,734690	0,265310	0,000000
745	0,734690	0,265310	0,000000
750	0,734690	0,265310	0,000000
755	0,734690	0,265310	0,000000
760	0,734690	0,265310	0,000000
765	0,734690	0,265310	0,000000
770	0,734690	0,265310	0,000000
775	0,734690	0,265310	0,000000
780	0,734690	0,265310	0,000000
785	0,734690	0,265310	0,000000
790	0,734690	0,265310	0,000000
795	0,734690	0,265310	0,000000
800	0,734690	0,265310	0,000000
805	0,734690	0,265310	0,000000
810	0,734690	0,265310	0,000000
815	0,734690	0,265310	0,000000
820	0,734690	0,265310	0,000000
825	0,734690	0,265310	0,000000

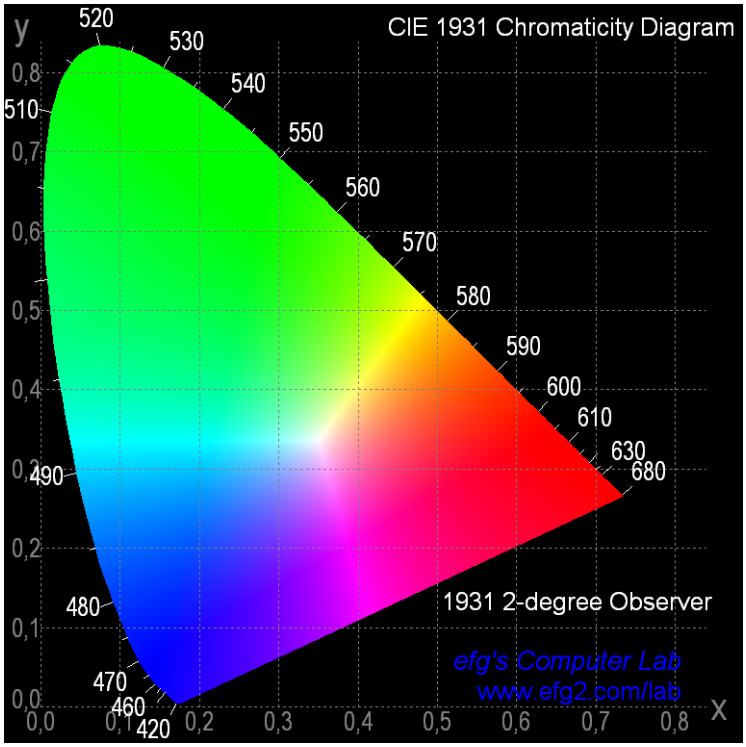
λ [nm]	x_λ	y_λ	z_λ
830	0,734690	0,265310	0,000000

Tabela 2: Współrzędne trójchromatyczne CIE XYZ 1931

1.2. Wykres chromatyczności

Światła widzialne w przestrzeni CIE XYZ zawarte są w bryle o kształcie zbliżonym do stożka o wierzchołku w początku układu współrzędnych. Całość bryły znajduje się w pierwszym oktancie. Jednak w praktyce stosuje się tzw. wykres chromatyczności (ang. *chromaticity diagram*), uzyskiwany poprzez rzutowanie płaszczyzny $x + y + z = 1$, która przecina bryłę CIE XYZ, na płaszczyznę $Z = 0$.

Wykres chromatyczności dla obserwatora CIE 1931 przedstawiono na rysunku 2. Na brzegu obszaru rozmieszczone są nasycone barwy widmowe określone przez dominujące długości fal.



Rysunek 2. Wykres chromatyczności CIE XYZ 1931

Wnętrze obszaru wraz z brzegiem reprezentuje wszystkie widzialne kombinacje wartości współrzędnych x, y. Barwy o tych samych współrzędnych trójchromatycznych, lecz o różnych luminacjach reprezentowane są przez ten sam punkt na wykresie chromatyczności. Zatem wykres nie zawiera pełnej palety barw, np. barwa brązowa czyli barwa pomarańczowoczerwona o małej luminacji występuje w innym przekroju bryły CIE XYZ. Standardowe światło białe przybliżające światło słoneczne, nazywane bielą C, ma współrzędne $x = 0,310$, $y = 0,316$, $z = 0,374$. Biel równoenergetyczna E ma w tym układzie wszystkie trzy współrzędne równe ($x = y = z = \frac{1}{3}$).

Wykres chromatyczności posiada cechy przydatne przy addytywnym mieszaniu barw. Addytywne zmieszanie barw reprezentowanych przez współrzędne trójchromatyczne (x_1, y_1) i (x_2, y_2) da barwę (x_3, y_3), która leży na odcinku łączącym punkty reprezentujące mieszane barwy. Położenie punktu (x_3, y_3) będzie zależało od proporcji, w jakich zostaną zmieszane barwy początkowe. Przykładowo jeżeli jako barwy początkowe zostaną wybrane barwa biała i odcień barwy nasyconej, reprezentowanej przez punkt leżący na brzegu wykresu chromatyczności, to na odcinku łączącym te barwy znajdują się wszystkie nienasycone odcienie barwy pierwotnej.

1.3. Transformacja CIE XYZ - CIE RGB

Transformację składowych trójchromatycznych układów CIE RGB i CIE XYZ można przedstawić w postaci poniższego równania:

$$\begin{pmatrix} x \\ y \\ z \end{pmatrix} = \begin{pmatrix} 0,49000 & 0,31000 & 0,20000 \\ 0,17697 & 0,81240 & 0,01063 \\ 0,00000 & 0,01000 & 0,99000 \end{pmatrix} \begin{pmatrix} r \\ g \\ b \end{pmatrix}$$

Jak łatwo sprawdzić macierz transformacji spełnia warunki zachowania równości składowych trójchromatycznych w obu układach dla światła o barwie białej E ($x = y = z = \frac{1}{3}$).

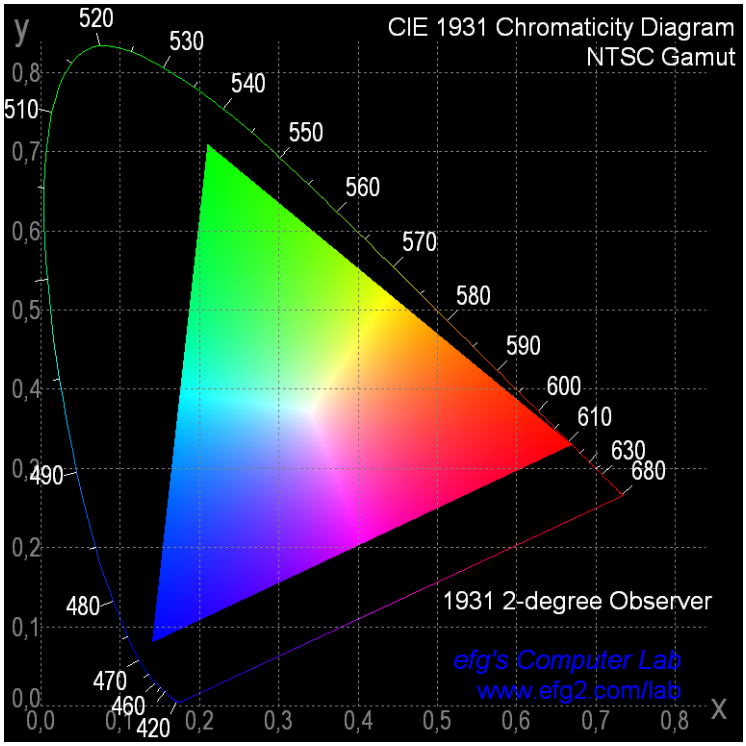
1.4. Gamy barw

Zasadę mieszania dwóch barw można rozszerzyć na trzy barwy, których współrzędne trójchromatyczne nie leżą na jednej prostej. W takim przypadku wszystkie możliwe do uzyskania barwy leżą wewnątrz trójkąta o wierzchołkach określonych przez barwy pierwotne. W szczególności może to dotyczyć przestrzeni barw RGB.

Porównamy dwa układy kolorymetryczne stosowane powszechnie w telewizji kolorowej. Pierwszy to układ RGB FCC, opracowany w 1951 roku przez FCC (ang. *Federal Communication Commission*) na potrzeby systemu NTSC. Drugi porównywanym układem jest RGB EBU opracowany

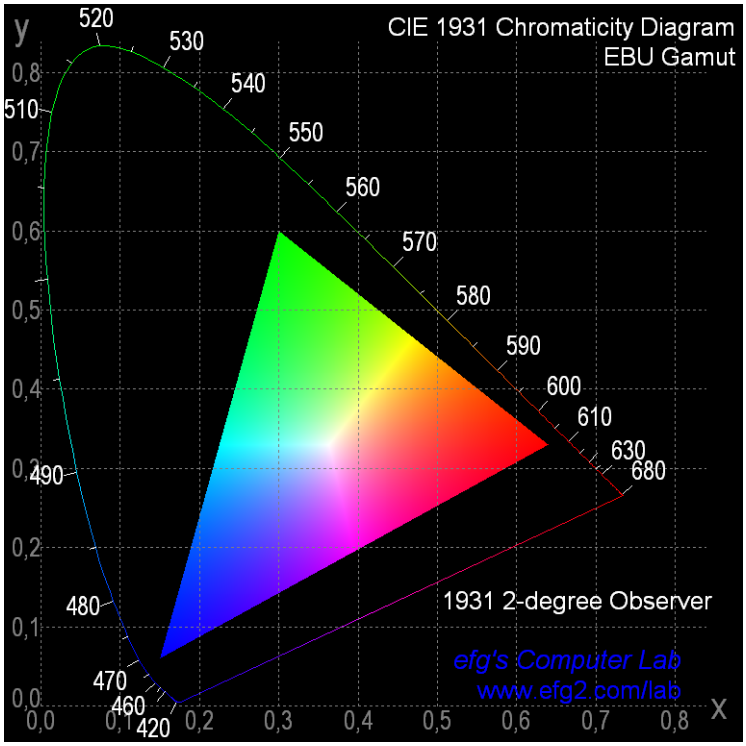
w 1970 roku przez brytyjskie stowarzyszenie EBU (ang. *European Broadcasting Union*) na podstawie przeciętnych barw luminoforów stosowanych w odbiornikach telewizyjnych.

Zakresy barw możliwych do wyświetlenia przez powyższe urządzenia (ang. *gamut*) wykreślimy na diagramie chromatyczności CIE XYZ. Przedstawiają to rysunki 3 i 4. Jak widać z powyższych rysunków powierzchnia trójkąta RGB EBU jest niewiele mniejsza od powierzchni trójkąta RGB FCC. Układ RGB EBU ogranicza nieco gamę odtwarzanych zieleni, dając jednocześnie pewną poprawę w zakresie barw o krótszych dominujących długościach fali.



Rysunek 3. Gama barw RGB FCC

Powyższy przykład obrazuje jeden z podstawowych problemów w reprodukcji barw - niezgodność gamy barw osiągalnych przez różne urządzenia. Różnorodne techniki rozwiązania tego problemu Czytelnik pozna w następnych rozdziałach.



Rysunek 4. Gama barw RGB EBU

1.5. Konwersja CIE XYZ - RGB FCC - RGB EBU

Konwersję pomiędzy układami CIE XYZ, RGB FCC i RGB EBU przedstawiają poniższe równania.

$$\begin{pmatrix} x \\ y \\ z \end{pmatrix} = \begin{pmatrix} 0,607 & 0,174 & 0,2 \\ 0,299 & 0,587 & 0,114 \\ 0 & 0,066 & 1,116 \end{pmatrix} \begin{pmatrix} r_{FCC} \\ g_{FCC} \\ b_{FCC} \end{pmatrix}$$

$$\begin{pmatrix} r_{FCC} \\ g_{FCC} \\ b_{FCC} \end{pmatrix} = \begin{pmatrix} 1,910 & -0,532 & -0,288 \\ -0,985 & 1,999 & -0,028 \\ 0,058 & -0,118 & 0,898 \end{pmatrix} \begin{pmatrix} x \\ y \\ z \end{pmatrix}$$

$$\begin{pmatrix} x \\ y \\ z \end{pmatrix} = \begin{pmatrix} 0,429 & 0,343 & 0,178 \\ 0,222 & 0,707 & 0,071 \\ 0,019 & 0,132 & 0,939 \end{pmatrix} \begin{pmatrix} r_{EBU} \\ g_{EBU} \\ b_{EBU} \end{pmatrix}$$

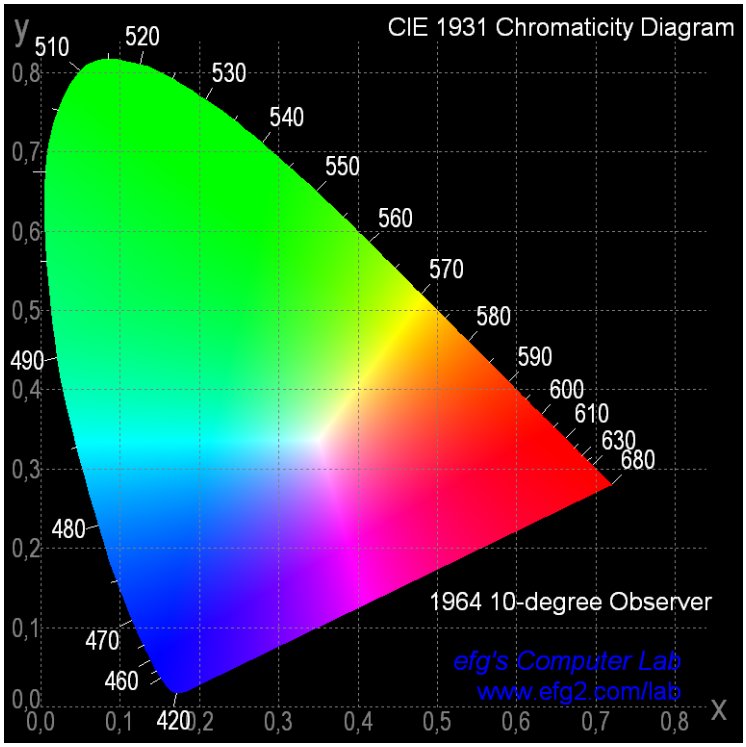
$$\begin{pmatrix} r_{EBU} \\ g_{EBU} \\ b_{EBU} \end{pmatrix} = \begin{pmatrix} 3,073 & -1,403 & -0,475 \\ -0,970 & 1,877 & 0,042 \\ 0,074 & -0,235 & 1,068 \end{pmatrix} \begin{pmatrix} x \\ y \\ z \end{pmatrix}$$

1.6. CIE XYZ 1964

W 1964 roku CIE opracowała model normalnego obserwatora CIE 10°, o kącie obserwacji 10°. Użycie tego obserwatora jest zalecane przy kątach obserwacji przekraczających 4°. Opracowanie tego modelu związane było z krytyką, iż typowy obserwator patrzy zwykle z kątem większym niż 4°.

Zastosowanie tego obserwatora spowodowało konieczność przeliczenia wartości współrzędnych trójchromatycznych i składowych trójchromatycznych widmowych układu CIE XYZ. Nowy układ funkcjonuje pod nazwą CIE XYZ 1964 lub CIE $X_{10}Y_{10}Z_{10}$.

Rysunek 5 przedstawia wykres chromatyczności CIE XYZ 1964.



Rysunek 5. Wykres chromatyczności CIE XYZ 1964

Tabela 3 przedstawia składowe widmowe CIE XYZ 1964 (wartości co 5 nm). Tabela 4 przedstawia współrzędne trójchromatyczne CIE XYZ 1964 (wartości także co 5 nm).

λ [nm]	$\bar{x}_\lambda$	$\bar{y}_\lambda$	$\bar{z}_\lambda$
360	0,000000122200	0,000000013398	0,000000535027
365	0,000000919270	0,000000100650	0,000004028300
370	0,000005958600	0,000000651100	0,000026143700
375	0,000033266000	0,000003625000	0,000146220000
380	0,000159952000	0,000017364000	0,000704776000
385	0,000662440000	0,000071560000	0,002927800000
390	0,002361600000	0,000253400000	0,010482200000
395	0,007242300000	0,000768500000	0,032344000000
400	0,019109700000	0,002004400000	0,086010900000
405	0,043400000000	0,004509000000	0,197120000000
410	0,084736000000	0,008756000000	0,389366000000
415	0,140638000000	0,014456000000	0,656760000000
420	0,204492000000	0,021391000000	0,972542000000
425	0,264737000000	0,029497000000	1,282500000000
430	0,314679000000	0,038676000000	1,553480000000
435	0,357719000000	0,049602000000	1,798500000000
440	0,383734000000	0,062077000000	1,967280000000
445	0,386726000000	0,074704000000	2,027300000000
450	0,370702000000	0,089456000000	1,994800000000
455	0,342957000000	0,106256000000	1,900700000000
460	0,302273000000	0,128201000000	1,745370000000
465	0,254085000000	0,152761000000	1,554900000000
470	0,195618000000	0,185190000000	1,317560000000
475	0,132349000000	0,219940000000	1,030200000000
480	0,080507000000	0,253589000000	0,772125000000
485	0,041072000000	0,297665000000	0,570600000000
490	0,016172000000	0,339133000000	0,415254000000
495	0,005132000000	0,395379000000	0,302356000000
500	0,003816000000	0,460777000000	0,218502000000
505	0,015444000000	0,531360000000	0,159249000000
510	0,037465000000	0,606741000000	0,112044000000
515	0,071358000000	0,685660000000	0,082248000000
520	0,117749000000	0,761757000000	0,060709000000
525	0,172953000000	0,823330000000	0,043050000000
530	0,236491000000	0,875211000000	0,030451000000
535	0,304213000000	0,923810000000	0,020584000000
540	0,376772000000	0,961988000000	0,013676000000

λ [nm]	$\bar{x}_\lambda$	$\bar{y}_\lambda$	$\bar{z}_\lambda$
545	0,451584000000	0,982200000000	0,007918000000
550	0,529826000000	0,991761000000	0,003988000000
555	0,616053000000	0,999110000000	0,001091000000
560	0,705224000000	0,997340000000	0,000000000000
565	0,793832000000	0,982380000000	0,000000000000
570	0,878655000000	0,955552000000	0,000000000000
575	0,951162000000	0,915175000000	0,000000000000
580	1,014160000000	0,868934000000	0,000000000000
585	1,074300000000	0,825623000000	0,000000000000
590	1,118520000000	0,777405000000	0,000000000000
595	1,134300000000	0,720353000000	0,000000000000
600	1,123990000000	0,658341000000	0,000000000000
605	1,089100000000	0,593878000000	0,000000000000
610	1,030480000000	0,527963000000	0,000000000000
615	0,950740000000	0,461834000000	0,000000000000
620	0,856297000000	0,398057000000	0,000000000000
625	0,754930000000	0,339554000000	0,000000000000
630	0,647467000000	0,283493000000	0,000000000000
635	0,535110000000	0,228254000000	0,000000000000
640	0,431567000000	0,179828000000	0,000000000000
645	0,343690000000	0,140211000000	0,000000000000
650	0,268329000000	0,107633000000	0,000000000000
655	0,204300000000	0,081187000000	0,000000000000
660	0,152568000000	0,060281000000	0,000000000000
665	0,112210000000	0,044096000000	0,000000000000
670	0,081260600000	0,031800400000	0,000000000000
675	0,057930000000	0,022601700000	0,000000000000
680	0,040850800000	0,015905100000	0,000000000000
685	0,028623000000	0,011130300000	0,000000000000
690	0,019941300000	0,007748800000	0,000000000000
695	0,013842000000	0,005375100000	0,000000000000
700	0,009576880000	0,003717740000	0,000000000000
705	0,006605200000	0,002564560000	0,000000000000
710	0,004552630000	0,001768470000	0,000000000000
715	0,003144700000	0,001222390000	0,000000000000
720	0,002174960000	0,000846190000	0,000000000000
725	0,001505700000	0,000586440000	0,000000000000
730	0,001044760000	0,000407410000	0,000000000000
735	0,000727450000	0,000284041000	0,000000000000
740	0,000508258000	0,000198730000	0,000000000000
745	0,000356380000	0,000139550000	0,000000000000

λ [nm]	$\bar{x}_\lambda$	$\bar{y}_\lambda$	$\bar{z}_\lambda$
750	0,000250969000	0,000098428000	0,000000000000
755	0,000177730000	0,000069819000	0,000000000000
760	0,000126390000	0,000049737000	0,000000000000
765	0,000090151000	0,000035540500	0,000000000000
770	0,000064525800	0,000025486000	0,000000000000
775	0,000046339000	0,000018338400	0,000000000000
780	0,000033411700	0,000013249000	0,000000000000
785	0,000024209000	0,000009619600	0,000000000000
790	0,000017611500	0,000007012800	0,000000000000
795	0,000012855000	0,000005129800	0,000000000000
800	0,000009413630	0,000003764730	0,000000000000
805	0,000006913000	0,000002770810	0,000000000000
810	0,000005093470	0,000002046130	0,000000000000
815	0,000003767100	0,000001516770	0,000000000000
820	0,000002795310	0,000001128090	0,000000000000
825	0,000002082000	0,000000842160	0,000000000000
830	0,000001553140	0,000000629700	0,000000000000

Tabela 3: Składowe widmowe CIE XYZ 1964

λ [nm]	x_λ	y_λ	z_λ
360	0,182218	0,019978	0,797804
365	0,182098	0,019938	0,797964
370	0,181923	0,019879	0,798198
375	0,181671	0,019797	0,798532
380	0,181333	0,019685	0,798982
385	0,180906	0,019542	0,799552
390	0,180313	0,019348	0,800339
395	0,179466	0,019044	0,801491
400	0,178387	0,018711	0,802902
405	0,177122	0,018402	0,804476
410	0,175488	0,018134	0,806378
415	0,173231	0,017806	0,808963
420	0,170634	0,017849	0,811517
425	0,167902	0,018708	0,813390
430	0,165027	0,020283	0,814690
435	0,162170	0,022487	0,815343
440	0,159022	0,025725	0,815253
445	0,155391	0,030017	0,814592
450	0,151001	0,036439	0,812560

λ [nm]	x_λ	y_λ	z_λ
455	0,145945	0,045217	0,808838
460	0,138922	0,058920	0,802158
465	0,129520	0,077870	0,792610
470	0,115180	0,109040	0,775780
475	0,095732	0,159090	0,745178
480	0,072777	0,229239	0,697984
485	0,045167	0,327343	0,627490
490	0,020987	0,440113	0,538900
495	0,007302	0,562523	0,430175
500	0,005586	0,674543	0,319871
505	0,021874	0,752578	0,225548
510	0,049540	0,802302	0,148157
515	0,085024	0,816976	0,098000
520	0,125236	0,810194	0,064569
525	0,166408	0,792172	0,041421
530	0,207057	0,766282	0,026661
535	0,243642	0,739873	0,016486
540	0,278588	0,711300	0,010112
545	0,313230	0,681278	0,005492
550	0,347296	0,650090	0,002614
555	0,381161	0,618164	0,000675
560	0,414213	0,585787	0,000000
565	0,446924	0,553076	0,000000
570	0,479038	0,520962	0,000000
575	0,509641	0,490359	0,000000
580	0,538560	0,461440	0,000000
585	0,565444	0,434556	0,000000
590	0,589960	0,410040	0,000000
595	0,611597	0,388403	0,000000
600	0,630629	0,369371	0,000000
605	0,647127	0,352873	0,000000
610	0,661224	0,338776	0,000000
615	0,673055	0,326945	0,000000
620	0,682660	0,317340	0,000000
625	0,689759	0,310241	0,000000
630	0,695483	0,304517	0,000000
635	0,700989	0,299011	0,000000
640	0,705873	0,294127	0,000000
645	0,710249	0,289751	0,000000
650	0,713713	0,286287	0,000000
655	0,715619	0,284381	0,000000

λ [nm]	x_λ	y_λ	z_λ
660	0,716790	0,283210	0,000000
665	0,717887	0,282113	0,000000
670	0,718732	0,281268	0,000000
675	0,719344	0,280656	0,000000
680	0,719763	0,280237	0,000000
685	0,720016	0,279984	0,000000
690	0,720160	0,279840	0,000000
695	0,720296	0,279704	0,000000
700	0,720358	0,279642	0,000000
705	0,720324	0,279676	0,000000
710	0,720227	0,279773	0,000000
715	0,720090	0,279910	0,000000
720	0,719911	0,280089	0,000000
725	0,719694	0,280306	0,000000
730	0,719447	0,280553	0,000000
735	0,719186	0,280814	0,000000
740	0,718906	0,281094	0,000000
745	0,718609	0,281391	0,000000
750	0,718292	0,281708	0,000000
755	0,717959	0,282041	0,000000
760	0,717607	0,282393	0,000000
765	0,717240	0,282760	0,000000
770	0,716859	0,283141	0,000000
775	0,716464	0,283536	0,000000
780	0,716057	0,283943	0,000000
785	0,715637	0,284363	0,000000
790	0,715208	0,284792	0,000000
795	0,714770	0,285230	0,000000
800	0,714325	0,285675	0,000000
805	0,713872	0,286128	0,000000
810	0,713411	0,286589	0,000000
815	0,712943	0,287057	0,000000
820	0,712471	0,287529	0,000000
825	0,711999	0,288001	0,000000
830	0,711523	0,288477	0,000000

Tabela 4: Współrzędne trójchromatyczne CIE XYZ 1964

1.7. Dodatek - tabele wartości składowych widmowych i współrzędnych trójchromatycznych

Przedstawione poniżej pliki nagłówkowe zawierają wartości składowych widmowych i współrzędnych trójchromatycznych układów CIE XYZ 1931 i CIE XYZ 1964 (wartości co 1 nm). Dane zawarte są w tabeli ze strukturami *CIE_XYZ*.

1.7.1. Plik cie_xyz.h

```
// (c) Janusz Ganczarski (Power)
// http://www.januszg.hg.pl
// JanuszG@enter.net.pl

#ifndef __CIE_XYZ__
#define __CIE_XYZ__

// definicja struktury do przechowywania wartości współrzędnych
// trójchromatycznych i składowych widmowych modelu CIE XYZ

struct CIE_XYZ
{
  int wavelength;
  double x,y,z;
};

#endif // __CIE_XYZ__
```

1.7.2. Plik ccciexyz_1931.h

```
// (c) Janusz Ganczarski (Power)
// http://www.januszg.hg.pl
// JanuszG@enter.net.pl

#ifndef __CCIEXYZ_1931_H__
#define __CCIEXYZ_1931_H__

#include "cie_xyz.h"

// współrzędne trójchromatyczne CIE XYZ 1931
// (ang. chromaticity coordinates)

const CIE_XYZ CC_CIE_XYZ_1931 [471] =
{
  { 360, 0.175560, 0.005294, 0.819146 },
  { 361, 0.175483, 0.005286, 0.819231 },
  { 362, 0.175400, 0.005279, 0.819321 },
  { 363, 0.175317, 0.005271, 0.819412 },
  { 364, 0.175237, 0.005263, 0.819500 },
  { 365, 0.175161, 0.005256, 0.819582 },
  { 366, 0.175088, 0.005247, 0.819665 },
  { 367, 0.175015, 0.005236, 0.819749 },
  { 368, 0.174945, 0.005226, 0.819829 },
  { 369, 0.174880, 0.005221, 0.819899 },
  { 370, 0.174821, 0.005221, 0.819959 },
  { 371, 0.174770, 0.005229, 0.820001 },
  { 372, 0.174722, 0.005238, 0.820040 },
  { 373, 0.174665, 0.005236, 0.820098 },
  { 374, 0.174595, 0.005218, 0.820187 },
  { 375, 0.174510, 0.005182, 0.820309 },
  { 376, 0.174409, 0.005127, 0.820464 },
  { 377, 0.174308, 0.005068, 0.820624 },
  { 378, 0.174222, 0.005017, 0.820761 },
  { 379, 0.174156, 0.004981, 0.820863 },
  { 380, 0.174112, 0.004964, 0.820924 },
  { 381, 0.174088, 0.004964, 0.820948 },
  { 382, 0.174073, 0.004973, 0.820955 },
  { 383, 0.174057, 0.004982, 0.820961 },
  { 384, 0.174036, 0.004986, 0.820978 },
  { 385, 0.174008, 0.004981, 0.821012 },
  { 386, 0.173972, 0.004964, 0.821064 },
```

```
{ 387, 0.173932, 0.004943, 0.821125 },
{ 388, 0.173889, 0.004926, 0.821185 },
{ 389, 0.173845, 0.004916, 0.821239 },
{ 390, 0.173801, 0.004915, 0.821284 },
{ 391, 0.173754, 0.004925, 0.821321 },
{ 392, 0.173705, 0.004937, 0.821358 },
{ 393, 0.173655, 0.004944, 0.821401 },
{ 394, 0.173606, 0.004940, 0.821454 },
{ 395, 0.173560, 0.004923, 0.821517 },
{ 396, 0.173514, 0.004895, 0.821590 },
{ 397, 0.173468, 0.004865, 0.821667 },
{ 398, 0.173424, 0.004836, 0.821740 },
{ 399, 0.173380, 0.004813, 0.821807 },
{ 400, 0.173337, 0.004797, 0.821866 },
{ 401, 0.173291, 0.004786, 0.821923 },
{ 402, 0.173238, 0.004779, 0.821983 },
{ 403, 0.173174, 0.004775, 0.822051 },
{ 404, 0.173101, 0.004774, 0.822125 },
{ 405, 0.173021, 0.004775, 0.822204 },
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{ 407, 0.172843, 0.004791, 0.822366 },
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{ 409, 0.172662, 0.004802, 0.822536 },
{ 410, 0.172577, 0.004799, 0.822624 },
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{ 414, 0.172192, 0.004815, 0.822993 },
{ 415, 0.172087, 0.004833, 0.823081 },
{ 416, 0.171982, 0.004855, 0.823163 },
{ 417, 0.171871, 0.004889, 0.823240 },
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{ 420, 0.171407, 0.005102, 0.823490 },
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};

#endif // __CCIEXYZ_1931_H__
```

1.7.3. Plik ccciexyz_1964.h

```
// (c) Janusz Ganczarski (Power)
// http://www.januszg.hg.pl
// JanuszG@enter.net.pl

#define __CCCIEXYZ_1964_H__
#define __CCCIEXYZ_1964_H__

#include "cie_xyz.h"

// współrzędne trójchromatyczne CIE XYZ 1964
// (ang. chromaticity coordinates)

const CIE_XYZ CC_CIE_XYZ_1964 [471] =
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  { 812, 0.713224, 0.286776, 0.000000 },
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  { 829, 0.711619, 0.288381, 0.000000 },
  { 830, 0.711523, 0.288477, 0.000000 }
};

#endif // __CCCIEXYZ_1964_H__
```

1.7.4. Plik ciexyz_1931.h

```
// (c) Janusz Ganczarski (Power)
// http://www.januszg.hg.pl
// JanuszG@enter.net.pl

#ifndef __CIEXYZ_1931_H__
#define __CIEXYZ_1931_H__

#include "cie_xyz.h"

// skladowe widmowe CIE XYZ 1931
// (ang. spectral values)

const CIE_XYZ SV_CIE_XYZ_1931 [471] =
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};

#endif // __CIEXYZ_1931_H__
```

1.7.5. Plik ciexyz_1964.h

```
// (c) Janusz Ganczarski (Power)
// http://www.januszg.hg.pl
// JanuszG@enter.net.pl

#ifndef __CIEXYZ_1964_H__
#define __CIEXYZ_1964_H__

#include "cie_xyz.h"

// składowe widmowe CIE XYZ 1964
// (ang. spectral values)

const CIE_XYZ SV_CIE_XYZ_1964 [471] =
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  { 362,  0.000000278830,  0.000000030560,  0.000001221200 },
  { 363,  0.000000417470,  0.000000045740,  0.000001828700 },
  { 364,  0.000000621330,  0.000000068050,  0.000002722200 },
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#endif // __CIEXYZ_1964_H__
```

Literatura

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