Klasifikacija moždanih tumora iz MRI snimaka

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*Sažetak*—Klasifikacija MRI snimaka ima velik potencijal u medicinskoj dijagnostici i istraživanjima. U ovom radu su isprobani različiti pristupi višeklasne klasifikacije moždanih tumora na temelju javno dostupnog skupa snimki dobivenih magnetskom rezonancijom. Slike prikazuju jednu od 3 vrste tumora (gliomi, meningeomi, tumor hipofize) ili mozak bez tumora. Za klasifikaciju slika najčešće se koriste konvolucijske neuronske mreže, u ovom su radu isprobane 2 arhitekture konvolucijskih neuronskih mreža: EfficientNetV2L i GoogLeNet. Osim navedenih mreža čije se treniranje temelji na prijenosnom učenju, isproban je i tradicionalan model strojnog učenja: stroj potpornih vektora (SVM). Najbolje rezultate dala je arhitektura EfficientNetVL2, sa značajno većom točnosti od arhitekture GoogLeNet. Model SVM je očekivano značajno lošije preciznosti od modela dubokog učenja koji se danas učestalo rabe pri različitim problemima klasifikacije slika.

Ključne riječi – višeklasna klasifikacija tumora mozga, MRI, duboko učenje, SVM, konvolucijske neuronske mreže, prijenosno učenje

# uvod

Značajan razvoj računarske znanosti i tehnologija medicinskog oslikavanja u posljednjim desetljećima omogućio je primjenu strojnog učenja u medicinskoj dijagnostici i istraživanju različitih bolesti. Poboljšanja u području grafičkih procesora i veći broj označenih skupova medicinskih slika također doprinose uspješnoj klasifikaciji slika. Sve precizniji klasifikacijski algoritmi, prvenstveno oni temeljeni na neuronskim mrežama, mogli bi pomoći radiolozima i drugim medicinskim djelatnicima pri analizi nalaza pacijenata.

U ovome radu provedena je višeklasna klasifikacija slika moždanih tumora dobivenih magnetskom rezonancijom. Tumori mozga čine 85% - 90% tumora centralnog živčanog sustava te se procjenjuje da je 2020. godine na svjetskoj razini dijagnosticirano 308 120 tumora mozga i kralježnične moždine [1]. Danas se magnetska rezonancija koristi za snimanje anatomije i funkcije mozga, ali i drugih dijelova tijela jer omogućuje brzu akviziciju slike, nije invazivna, a većina ljudskih tkiva (osim primjerice, kostiju i pluća) sadrže vodik čija se prisutnost mjeri pri MRI snimanju. Magnetska rezonancija je relativno nov modalitet medicinskog snimanja temeljen na principima kvantne elektrodinamike. 1974. godine Peter Mansfield predstavio je matematičku teoriju iza medicinskog oslikavanja i registracije slike [2].

MRI snimke u ovom su radu klasificirane u jednu od 4 klase: 3 vrste tumora (*gliom, meningeom* ili *tumor hipofize*) i klasa *mozak bez tumora*. Za klasifikaciju slika mogu se koristiti i tradicionalni pristupi strojnog učenja poput modela stroja potpornih vektora (engl. *support vector machine*), ali i tehnike dubokog učenja, prvenstveno konvolucijske neuronske mreže, koje su se pokazale primjerenijima za zadatke poput segmentacije i klasifikacije medicinskih slika. Prije klasifikacije slika modelima temeljenim na prijenosnom učenju, isproban je klasifikator SVM koji, očekivano, nije dao zadovoljavajuće rezultate. Rezultati bi se potencijalno mogli poboljšati kvalitetnijim pristupom ekstrakcije značajki, ali u ovom je radu stavljen naglasak na primjenu konvolucijskih neuronskih mreža jer one imaju ugrađenu ekstrakciju značajki, što je jedan od razloga njihove česte primjene za ovu vrstu klasifikacijskog problema. Koristili smo 2 poznate arhitekture neuronskih mreža: EfficientNetV2L i GoogLeNet. Navedene mreže, čije su inicijalne težine dobivene treniranjem na velikoj bazi slika ImageNet, primjer su prijenosnog učenja koje se pokazalo vrlo uspješnim u ovom području primjene.

U nastavku rada dan je pregled postojećih pristupa klasifikacije slika moždanih tumora. U trećem poglavlju opisana je metodologija rada, a u četvrtom poglavlju predstavljeni su dobiveni rezultati. Peto poglavlje sadrži diskusiju dobivenih rezultata, a zaključak rada je naveden u šestom poglavlju.

# Pregled postojećih pristupa klasifikacije slika moždanih tumora

Zadatci klasifikacije slika moždanih tumora mogu se svrstati u 2 kategorije:

* binarna klasifikacija tumora
* višeklasna klasifikacija tumora

Zadatak binarne klasifikacije tumora mozga može biti: određivanje je li tumor na slici benigan ili maligan, ima li na mozgu tumora ili ne, je li tumor višeg ili nižeg stupnja. Višeklasna klasifikacija tumora podrazumijeva određivanje kojoj vrsti tumora slika pripada. U mnogim se radovima koristi javno dostupan podatkovni skup iz 2017. koji sadrži slike 3 vrste tumora [3]: gliomi (engl. glioma), meningeomi (engl. meningioma) i tumor hipofize (engl. pituitary tumor). Podatkovni skup odabran u ovom radu također sadrži ove 3 klase, ali i četvrtu klasu: slike mozga bez tumora [4].

Moderni pristupi klasifikacije slike oslanjaju se na duboko učenje. Najčešće se primjenjuju konvolucijske neuronske mreže [5] [6], a neki su radovi povezali modele dubokog prijenosnog učenja s tradicionalnim pristupima stojnog učenja kao što su algoritam SVM [7]. Dio znanstvenih članaka navodi i primjenu neparametarskog tradicionalnog modela k-NN [8] [9]. Pregled postojećih pristupa klasifikacije slika tumora mozga sažeto je prikazan u Tablici I.

Tablica I. PREGLED POSTOJEĆIH PRISTUPA KLASIFIKACIJE SLIKA TUMORA MOZGA

|  |  |  |  |
| --- | --- | --- | --- |
| ISTRAŽIVANJE | PODATKOVNI SKUP | METODOLOGIJA | TOČNOST |
| Chelghoum et al.  [5] | javno dostupan Figshare podatkovni skup [1] | - klasifikacija 3 vrste tumora mozga  - prijenosno učenje s 9 CNN arhitektura | najbolja točnost: 98.71 % (VGG-16, 90 epoha) |
| Das et al.  [6] | javno dostupan Figshare podatkovni skup [1] | - klasifikacija 3 vrste tumora mozga  - konvolucijska neuronska mreža (CNN) | 94.39 % |
| Kibriya et al.  [7] | javno dostupan Figshare podatkovni skup [1] | -klasifikacija 3 vrste tumora mozga (CNN + SVM klasifikator)  - 2 modela prijenosnog učenja: GoogLeNet i ResNet-18 | - 97.4 % (GoogLeNet)  - 97.8 % (Res-Net18)  - 97.6 %  (GoogLeNet + SVM)  - 98 %  (Res-Net + SVM) |
| Wasule et al.  [8] | snimke iz bolnice Sahyandri,  baza podataka BRATS (2012.) | - binarna klasifikacija tumora mozga (SVM i kNN klasifikator)  - ekstrakcija značajki: GLCM | - snimke iz bolnice: SVM: 96%  KNN: 86%  - BRATS:  SVM: 85%  KNN: 72.5% |
| Ramdlon et al. [9] | TCIA (The Cancer Imaging Archive) | - segmentacija  - ekstrakcija značajki: centroid i površina objekta  - klasifikacija 3 vrste tumora mozga algoritmom k-NN | 89,5 % |

U [5], [6], i [7] slike tumora mozga klasificiraju se u 3 grupe: gliomi, meningeomi i tumor hipofize. U [9] slike se klasificiraju u 3 grupe: astrocitomi (engl. Astrocytoma), glioblastomi (engl. Glioblastoma) i oligodendrogliomi (engl. Oligodendroglioma). U [8] se rade dvije binarne klasifikacije: određivanje je li tumor maligni ili benigni te klasifikacija glioma u gliom visokog i niskog stupnja.

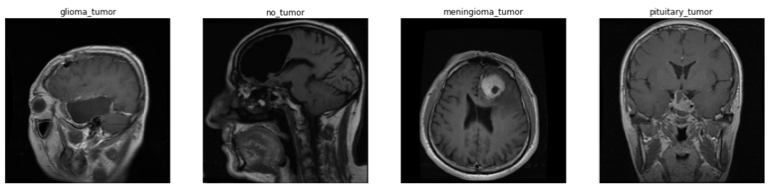
Prije provođenja klasifikacije potrebno je provesti predobradu slika. To obično podrazumijeva primjenu nekih od sljedećih postupaka: medijan filtar za uklanjanje šuma [8] [9], primjena Gaussova filtra za zaglađivanje slika [6], promjena veličine slika, transformacija intenziteta slika. U [7] je prije treniranja modela provedena min-max normalizacija intenziteta slika. U tom je radu također povećan podatkovni skup kako bi se izbjegli pristranost prema većinskoj klasi tumora koristeći pritom sljedeće tehnike: rotacija, zrcaljenje i dodavanje sol-papar šuma. U [5] su pak normalizirane izvorne slike i konvertirane u RGB format. Neki autori prije klasifikacije tumora provode segmentaciju slika s ciljem da detektirani objekti mozga (područje tumora) budu bijeli, a ostatak slike crn [9].

U [9] je provedena klasifikacija k-NN algoritmom. Korištene značajke su: centorid (na temelju x i y koordinata središta tumora određene su 2 diskretne koordinate tumora) i površina objekta (udio površine slike koju zauzima tumor). U [6] je osim algoritma k-Najbližih susjeda (k-NN) isproban i stroj potpornih vektora (SVM). Primijenjen je GLCM (engl. *Gray Level Co-occurence Matrix*) za ekstrakciju značajki. Neke od značajki koje se koriste u ovom i sličnim radovima su: kontrast, korelacija, entropija, energija i homogenost. Prema njihovim rezultatima stroj potpornih vektora se pokazao boljim klasifikatorom od algoritma k-NN.

Tradicionalni pristupi strojnog učenja zahtijevaju segmentaciju slika i/ili ekstrakciju značajki prije klasifikacije. Pri klasifikaciji slika danas se ipak najčešće koriste konvolucijske neuronske mreže. One predstavljaju model u kojem je ekstrakcija značajki ugrađena u model. Takozvani end-to-end modeli s prijenosnim učenjem (engl. *transfer learning*) postižu visoku točnost: 97.4 % (GoogLeNet) i 97.8 % (ResNet-18) [7]. Dobivene značajke su iskorištene za treniranje SVM klasifikatora koji je postigao točnost od 98 %. U [5] testirano je 9 CNN arhitektura uz prijenosno učenje: AlexNet, GoogleNet, VGG16, VGG19, Residual Networks (ResNet18, ResNet50, ResNet101), Residual Networks and Inception-v2 (ResNet-Inception-v2), Squeeze and Excitation Network (SENet). Temeljna je ideja prijenosnog učenja iskoristiti znanje naučeno na jednom skupu za učenje na drugim skupovima podataka. Mreže su trenirane stohastičkim gradijentnim spustom u skupinama (engl. *minibatch*) od 128 slika. Kao broj epoha isprobani su 25, 50 i 90, a pokazalo se da povećanje ne doprinosi značajno točnosti klasifikacije. Sve su arhitekture osim SENet postigle točnost veću od 90 % na 25 epoha. Također, pokazalo se da arhitekture s manje slojeva (AlexNet, GoogleNet, VGG-16) bolje klasificiraju. U [6] je trenirana neuronska mreža s 3 konvolucijska sloja s konvolucijskom jezgrom (engl. *kernel*) veličine 5x5 i s 2 sloja sažimanja (engl. *subsampling layer*) s veličinom podmatrice 2x2. Kako bi se smanjila prenaučenost korišteni su tzv. *dropout* *slojevi* u kojim se zanemaruje dio neurona u daljnjem prolazu kroz mrežu. Korištena su 2 gusta sloja (engl. *dense layer*), od kojih se zadnji koristi kao poveznica između konvolucijskih slojeva i *softmax* izlaznog sloja. Predloženi model postiže visoku točnost na skupu za ispitivanje: 94.39%. Ipak, rezultat je manji nego u radovima koji primjenjuju prijenosno učenje.

Većina istraživanja iz područja klasifikacije moždanih tumora pomoću MRI snimaka koristi konvolucijske mreže, a sve su popularniji pristupi prijenosnog učenja. Ekstrakcija ispravnih značajki i tradicionalni pristupi, poput stroja potpornih vektora i algoritma najbližih susjeda, mogu postići visoku točnost, ali ipak nižu od konvolucijskih neuronskih mreža. Od navedenih arhitektura najboljom se pokazala VGG-16 (točnost 98.71 %), ali treniranje u prosjeku traje 1950 minuta. S druge strane, treniranje mreže AlexNet u 90 epoha u prosjeku traje 91 minutu, a rezultira točnošću 98.22 % [5].

# metodologija

Za ovaj je rad odabran javno dostupan skup podataka sa stranice *Kaggle* [3]. Skup podataka sadrži 3264 slike mozga dobivene magnetskom rezonancijom. Slike su podijeljene u četiri klase: gliomi (engl. glioma), meningeomi (engl. meningioma), tumor hipofize (engl. pituitary tumor) i slike mozga bez tumora. Na slici 1. prikazana je po jedna slika za navedene tumore te prikaz slike mozga bez tumora. Može se primijetiti da su dobivene slike slikane iz različitih kuteva što konvolucijskim neuronskim mrežama omogućuje učenje različitih uzoraka pojedinog tumora.

Slika 1. Prikaz 3 vrste tumora mozga i mozga bez tumora (slike iz [3] )

Omjer klasa skupa podataka nije jednak. Najmanji dio slika pripada klasi slika bez tumora, a preostale tri klase imaju usporedive omjere, no najveća je klasa slika tumora meningeoma. Podatkovni skup je nasumično podijeljen na skup za treniranje i skup za testiranje u omjeru 80:20. Za to je korištena je funkcija *train\_test\_split.*

Chart, bar chart

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Slika 2. Distribucija tumora mozga u podatkovnom skupu

Kako bi se postigla što bolja točnost modela, slike su predobrađene po uzoru na navedene radove. Odabrano je uklanjanje šuma medijan filtrom te min-max normalizacija intenziteta slika. Slike su obrađene tako da sve budu istih dimenzija, no odabrane dimenzije se razlikuju za različite modele. Postupak učenja proveden je uz pomoć algoritama konvolucijskih neuronskih mreža i stroja potpornih vektora. Odabrane arhitekture za učenje pomoću konvolucijskih neuronskih mreža su GoogLeNet i EfficientNetV2L. Za implementaciju korištenih algoritama i predobradu slike korištene su biblioteke scikit-learn, OpenCV, TensorFlow i NumPy. Za izgrađene modele su ispisane neke mjere validacije kao što su odziv (engl. *recall*), preciznost (engl. *precision*) i F1-vrijednost (engl. *F1-score*) koja je kombinacije prethodne dvije. Također je prikazana točnost izgrađenih modela.

## GoogLeNet

GoogLeNet arhitektura temelji se na algoritmu dubokih konvolucijskih neuronskih mreža. Sastoji se od 22 sloja, točnije 27 slojeva ako računamo i slojeve udruživanja (engl. *pooling layers*), a 9 od njih su slojevi početnih modula (engl. *inception modules*). Odabrana veličina slika za izgradnju ovog modela je 224x224, što je preporučeno za GoogLeNet arhitekturu. Odabrani broj epoha je 25, a veličina grupe (engl. *batch size*) korištena u svakoj iteraciji je 30. Korištene aktivacijske funkcije su ReLu i softmax. Softmax se koristi samo kod izlaznog sloja kako bi se dobila vjerojatnost pripadnosti određenoj klasi. Učenje modela trajalo je 75 minuta.

## EfficientNetV2L

EfficientNetV2L arhitektura, kao i GoogLeNet zasnovana je na temelju konvolucijskih neuronskih mreža te generalno ima kraće vrijeme učenja modela (premda ovo nije zakon, kao što ćemo imati priliku vidjeti na našem primjeru) te veću efikasnost od svojih prethodnika. Obično koriste 3x3 ili 5x5 konvolucijsku jezgru, te je u našem primjeru sukladno korištena jezgra 3x3. Po uzoru na navedene pristupe klasifikaciji, odabran broj epoha je bio 10, dok je veličina grupe 32. Odabrana veličina slike je 112x112. Vrijeme treniranja trajalo je nešto više od 152 minute, a pretpostavka je da su odgovorni za to manji broj epoha od prethodne mreže kao i manja veličina slike.

## Stroj potpornih vektora

SVM ili stroj potpornih vektora (engl. *Support Vector Machine)* je vrlo učinkovit klasifikacijski i regresijski algoritam koji je dugo vremena dominirao na sceni strojnog učenja. SVM je linearan model koji pronalazi najbolju granicu za razdvajanje podataka u klase. Granica je odabrana kako bi se maksimizirala margina, što je udaljenost između granice i najbližih točaka iz svake klase. SVM koristi jezgreni trik kako bi projicirao podataka u prostor više dimenzije, gdje se mogu lako odvojiti. Veličina slika je 150x150 što je preporučeno za SVM. Učenje modela je trajalo 5 minuta što je iznimno brzo.

# rezultati

Mjere validacije koje su korištene za sva tri izgrađena modela su preciznost, odziv i F1-vrijednost. Preciznost je udio stvarno pozitivnih primjera u svim primjerima koji su klasificirani kao pozitivni, tj. . Odziv je udio pozitivno klasificiranih primjera u skupu svih koji su stvarno pozitivni, tj. . F1-vrijednost je definirana kao harmonijska sredina preciznosti i odziva, tj.

U nastavku su za svaki od tri izgrađena modela detaljno prikazani i opisani dobiveni rezultati.

## GoogLeNet

U tablici 1. vidljivo je da je preciznost najveća za klasu tumora meningeoma i iznosi 97%. To znači da od svih slika koje su klasificirane kao tumor meningeoma njih 97% to i jest. Odziv je najveći za klasu tumora hipofize te iznosi 99% što znači da od svih slika na kojima se nalazi tumor hipofize, njih 99% su točno klasificirane. Najmanju preciznost ima klasa tumor gliomi, a najmanji odziv klasa tumora meningeomi. F1-vrijednost je najbolja za klasu tumora hipofize i iznosi 97%. Za preostale klase F1-vrijednost iznosi 92%. Uočeno je da ako neka klasa ima bolju preciznost vrlo često će imati lošiji odziv te vrijedi i obrnuto.

Tablica 1. Prikaz mjera validacije za model izgrađen GoogLeNet arhitekturom

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| ***KLASA*** | ***preciznost*** | ***odziv*** | ***F1-vrijednost*** | ***količina*** |
| **bez tumora** | 0.95 | 0.90 | 0.92 | 107 |
| **meningeomi** | 0.97 | 0.88 | 0.92 | 208 |
| **gliomi** | 0.88 | 0.96 | 0.92 | 188 |
| **tumor hipofize** | 0.94 | 0.99 | 0.97 | 150 |

## EfficientNetV2L

U tablici 2. prikazani su rezultati treniranja pomoću *EfficientNetV2L*. Najveća preciznost postignuta je za tumore hipofize, a najveći odziv, i to čak 100%, postignut je za klasu bez tumora. F1-vrijednost ipak je najveća za klasu tumora hipofize. U ovom slučaju nije vidljiva negativna korelacija preciznosti i odziva.

Tablica 2. Prikaz mjera validacije za model izgrađen EfficientNetV2L arhitekturom

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| ***KLASA*** | ***preciznost*** | ***odziv*** | ***F1-vrijednost*** | ***količina*** |
| **bez tumora** | 0.96 | 1 | 0.98 | 98 |
| **meningeomi** | 0.97 | 0.98 | 0.98 | 201 |
| **gliomi** | 0.98 | 0.96 | 0.97 | 204 |
| **tumor hipofize** | 0.99 | 0.99 | 0.99 | 150 |

## Support vector machine

U tablici 3. prikazani su rezultati treniranja pomoću stroja potpornih vektora (SVM). Najveća je preciznost postignuta za klasu bez tumora, a najveći odziv i najveća F1-vrijednost postignuti su za klasu tumora hipofize.

Tablica 3. Prikaz mjera validacije za model izgrađen algoritmom SVM

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| ***KLASA*** | ***preciznost*** | ***odziv*** | ***F1-vrijednost*** | ***količina*** |
| **bez tumora** | 0.92 | 0.78 | 0.84 | 99 |
| **meningeomi** | 0.80 | 0.80 | 0.80 | 197 |
| **gliomi** | 0.78 | 0.78 | 0.79 | 171 |
| **tumor hipofize** | 0.89 | 0.96 | 0.92 | 186 |

![Chart, bar chart

Description automatically generated](data:image/jpeg;base64,/9j/4AAQSkZJRgABAQEAeAB4AAD/4RDuRXhpZgAATU0AKgAAAAgABAE7AAIAAAAMAAAISodpAAQAAAABAAAIVpydAAEAAAAYAAAQzuocAAcAAAgMAAAAPgAAAAAc6gAAAAgAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAFBldHJhIER1bmphAAAFkAMAAgAAABQAABCkkAQAAgAAABQAABC4kpEAAgAAAAMzMAAAkpIAAgAAAAMzMAAA6hwABwAACAwAAAiYAAAAABzqAAAACAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAA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Slika 3. Točnost klasifikatora na skupu za testiranje

Točnost isprobanih klasifikatora na skupu za testiranje je prikazana na slici 3. Model izgrađen pomoću *GoogLeNet* arhitekture ima ukupnu točnost od 93,3 %, model izgrađen pomoću EfficientNetV2L arhitekture ima ukupnu točnost od 97,9 %, a model izgrađen pomoću stroja potpornih vektora ima ukupnu točnost od 83,8 %.

# diskusija

Vidljivo je da je po svim korištenim metrikama model *EfficientNetV2L* dao najbolje rezultate. Dobivena točnost veća je od točnosti dobivene *GoogLeNet* modelom za 4,6 %. S obzirom na to da je u testnom skupu 653 slike, to predstavlja razliku u predviđanju na čak 30 slika.

Kao što je i očekivano, stroj potpornih vektora dao je značajno lošije rezultate, s točnosti od samo 83,8 %, što je za 9,5 % manje od *GoogLeNet* modela i čak 14,1 % manje od *EfficientNetV2L* modela.

Prikladno daljnje istraživanje moglo bi biti usmjereno na povećavanje i augmentaciju skupa podataka, bilo snimanjem novih slika, ili predobradom postojećih slika.

# zaključak

Klasifikacija medicinskih slika fokus je sve većeg broja znanstvenih članaka. Metode dubokog učenja, poput konvolucijskih mreža podržanih prijenosnim učenjem, uz asistenciju neuroznanstvenika mogle bi olakšati i ubrzati proces detekcije moždanih tumora. U ovom je radu naglasak bio na klasifikaciji MRI snimki mozga: radilo se o jednom od 3 vrste moždanih tumora (gliomi, meningeomi, tumor hipofize) ili o mozgu bez tumora.

Prije treniranja modela, provedena je predobrada slika: primijenjen je median filtar i min-max normalizacija intenziteta slika kako bi se uklonio šum i poboljšao kontrast slika. Na odabranom podatkovnom skupu trenirana su 3 modela: tradicionalni model strojnog učenja SVM i 2 arhitekture neuronskih mreža *GoogLeNet* i *EfficientNetVL2*. Kao i u većini znanstvenih radova, paradigma prijenosnog učenja i konvolucijske neuronske mreže su se pokazale prikladnijim klasifikatorom slika moždanih tumora od SVM-a.

Arhitektura *EfficientNetVL2* dala je najbolje rezultate, s točnosti 97,9 %. Nešto lošije rezultate dala je arhitektura *GoogLeNet*, s točnosti 93,3 %. Očekivano najmanju točnost dao je model SVM, 83,8 %.

Premda je skup podataka malen (3264 slika), postignuti su rezultati koji potvrđuju uspješnost konvolucijskih neuronskih mreža u klasifikacijskim zadatcima poput ovog. Očekuje se da će daljnji razvoj modela za klasifikaciju snimki tumora liječnicima olakšati analizu nalaza pacijenata i tako omogućiti pravovremenu i kvalitetnu medicinsku dijagnostiku.

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