Proceedings of the 21st International Conference on Global Research and Education (Inter-Academia 2024)

Telemedicine System Supporting Early Diagnosis and Efficient Therapy of Lyme Disease

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This work presents a telemedicine system designed to support the diagnosis of Lyme disease, a common and dangerous illness spread by ticks. The system was designed as a smartphone application and built in close cooperation with doctors specializing in diagnosing and treating Lyme disease. After logging in, a potential patient answers yes/no to a series of simple questions in a properly composed survey. Then, he is asked to take a photo of the skin lesion (erythema migrans) with a smartphone. The complete data set is sent to the contractual system administrator, and artificial intelligence performs a preliminary data analysis. As a result, the patient is sent information that the probability of the disease is low or high. The system advises seeing a specialist in high-risk cases for a complete diagnosis and treatment. Ignoring early symptoms can lead to severe complications in the later stages of the disease. The paper presents preliminary results of diagnoses made by neural networks. Despite being conducted on a small dataset, the research showed promising results with 93% accuracy. The conclusion highlights the system's practical applications and potential for similar uses.

topics: Lyme disease, telemedicine, convolutional neural network (CNN), skin lesion image classification

1. Introduction

Telemedicine is, according to the definition of ATA (*American Telemedicine Association*), "the exchange of medical information between two or more users using electronic communication to improve the health of patients." In this work, we describe the operation of a telemedicine system, which, in its original version, was dedicated to supporting the diagnosis of Lyme disease, a dangerous disease spread by ticks (see Fig. 1) [1], which is common in Poland. This disease has been known for over 100 years, but it was only in 1982 that Willy Burgdorfer discovered that it was caused by bacteria found in the intestines of these arachnids.

In Poland, the first case of Lyme disease was recorded in the 1990s, and the highest incidence was in 2017 (21 200 cases registered, although the total number of patients may be much higher). Currently, the number of infections significantly exceeds 10000 every year. The potential target group interested in using the system includes forestry workers, border services, tourists (especially children), forest undergrowth collectors, and indirectly, doctors and National Health Fund units.

Although statistically, only a few percent of tick bites result in infection, it should be mentioned that up to 30% of people do not notice that they have been bitten.

Fig. 1. Tick (Ixodida) (picture taken from [1], 2024, August 10).

At the same time, ignoring the infection, e.g., due to the varied symptoms of the disease, which are often similar to other ailments, may lead to a late stage that causes significant damage to health, is very difficult to cure, and sometimes even threatens the patient's life.

2. Lyme disease

As already stated, the symptoms of the disease are diverse and similar to other ailments [2, 3]. A commonly considered sure symptom of infection is the so-called erythema migrans (Fig. 2) [4]. It is a redness around the tick bite site, spreading

Fig. 2. Patterns of *erythema migrans* (EM) (picture taken from [4], 2024, August 10).

Fig. 3. Lymphocytic lymphoma (picture taken from [5], 2024, August 10).

peripherally, occurring in approximately 40–60% of infected people. The classic skin lesion has a diameter of over 5 cm and, in 9% of cases, shows central clearing.

In most patients, it does not cause any symptoms of burning, itching, or pain. Erythema migrans lasts 3–4 weeks and disappears without treatment. It develops around the tick bite site but may also appear on other body parts (often the groin or armpits) or may not occur at all. Another rare (several percent) symptom of the early stage of Lyme disease is cutaneous lymphocytic lymphoma (Fig. 3) [5]. It is usually a single nodule, quite small, red or bluish-red color, well demarcated from the surrounding skin, and painless. Its most common locations are the auricles, scrotum, and nipples.

According to the Polish Society of Epidemiologists and Infectious Disease Physicians, Lyme disease has three stages. In the first stage, following spirochete infection, early localized Lyme disease is diagnosed [6, 7].

Flu-like symptoms and the characteristic erythema migrans appear, which, as mentioned, may not occur, go unnoticed, or be ignored. It is worth adding that Lyme disease symptoms may appear even after a delay of several months or years following infection. Most patients do not associate their symptoms with a previous tick bite, making proper diagnosis difficult. The next stage of the disease is early disseminated Lyme disease (often referred to as the early organ stage). During this period, the disease can cause arthritis, myocarditis, or most commonly, paralysis of the facial nerve (which is responsible for the innervation of the facial muscles). Late Lyme disease is the final stage, where symptoms manifest in various organs. Dermatitis of the limbs, chronic arthritis, mild inflammation of muscles, bursae, or tendons, and worsening chronic neuroborreliosis with meningitis may occur. If treated early, immediately after being bitten by an infected tick, Lyme disease treatment involves administering antibiotics. However, if the disease is left untreated and progresses to the late stage, therapy becomes very difficult, symptomatic, and often requires rehabilitation.

Work on the system began in 2021, during the COVID-19 pandemic, when healthcare access in Poland was additionally restricted. This was related to the announcement of the Poland–East grant competition and the hope of securing research funding from it. As required, we established a startup (Bicadilly) and reached the final stage of the proceedings. However, our project lost due to a lower business potential, which was one of the basic requirements of the competition.

It should be noted that the issue of Lyme disease diagnosis has inspired many research teams in recent years, leading to several significant publications [8]. Among them, we would include [9], which focus on using deep learning neural networks to recognize skin lesions associated with Lyme disease and differentiate them from other types of lesions such as rashes or eczema. Particularly noteworthy is work [10], in which the authors provide a thorough review of publications on the automatic recognition of various types of medical images using artificial intelligence, including deep learning neural networks.

It is worth mentioning the IDERME app [11], which supports image search through artificial intelligence to help find the most relevant information. The algorithm performs a visual assessment smartphone photos of skin lesions and provides a range of information associated with the specific lesion based on information from wiki sites and PubMed. The algorithm has been developed and maintained by Han Seung Seog, a Korean dermatologist, with the help of many contributing researchers.

3. The data and methods

Considering the above, we decided to develop software to support the diagnosis of Lyme disease as a smartphone application running on the Android system. From the very beginning, all activities were consulted with the medical community. In addition to the mandatory formal parts regarding registration and login, the program includes a specialized survey. Here, just like during a visit to a specialist, the patient answers yes/no to a set of a dozen or so questions. After a positive answer to the question about the presence of a skin lesion, the patient is asked to take a photo of it using a smartphone camera. The software's user manual provides the conditions the submitted image should meet. The survey

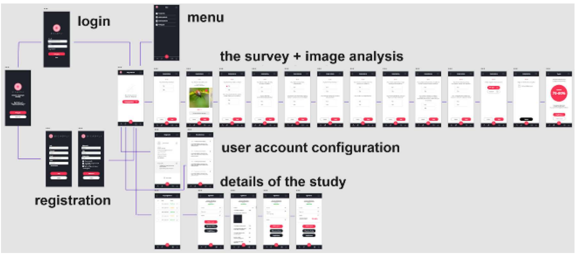

Fig. 4. The system prototype — use case diagram.

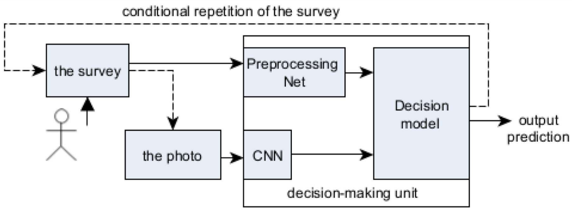

Fig. 5. The functional diagram of the decision-making system.

results and the photo (if taken) are sent to the analysis centre, where automatic data evaluation takes place. The use case diagram of the system prototype is shown in Fig. 4.

The survey, recorded in the first version of the program, contained 16 questions and is different for patients who were bitten — they saw the tick — and those who have strange symptoms but do not remember being bitten. For the former, the questions pertain to the time and manner of the tick bite, the duration of attachment, tick's appearance after detaching on its own, the method of removal, any skin changes, and the occurrence of unexpected symptoms (associated with Lyme disease). For patients who do not remember being bitten, the questions focus on unexpected symptoms such as fever, headache, swollen joints, muscle pain, sleep disturbances, etc. At the same time, the program emphasizes the importance of observing any potential skin changes.

Once the program is launched, even if the initial diagnosis indicates that the patient does not show symptoms of the disease, it will remain active for two or three months, providing reminders every two weeks and requiring the patient to complete the survey again. In this way, we aim to ensure that a positive result (infection) will not be missed due to the previously mentioned delayed onset of disease symptoms. A positive assessment — i.e., the determination that the patient is most likely infected — is communicated directly to the patient. At the same time, the system suggests a visit to a specialist. An appointment with a specific doctor can be automatically generated in the advanced version. Such a module was proposed in the Podlasie region, around Suwałki and Augustów.

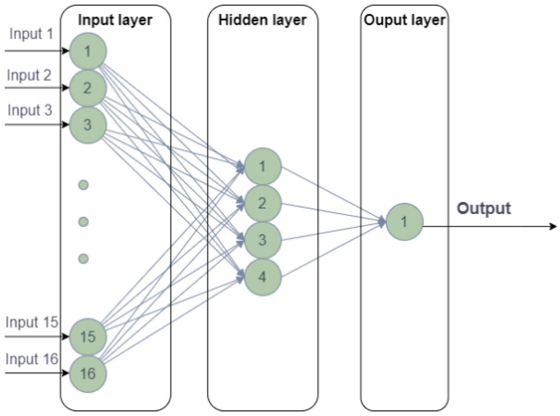

Fig. 6. The preprocessing net.

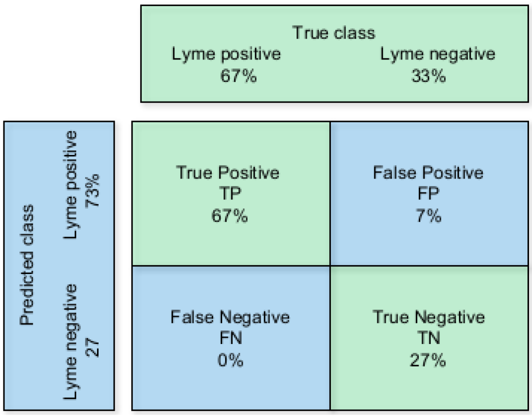

Fig. 7. Confusion matrix for the model.

The decision-making system, shown in Fig. 5, consists of a cooperating feedforward neural network (for which the binary vector of survey answers is an input signal, see Fig. 6) and a ResNet *convolutional neural network* (CNN) that evaluates the submitted photo (if one was taken) [12–15].

The preprocessing net shown in Fig. 5 is a classic feedforward network. Its construction is illustrated in Fig. 6. The network has 16 inputs, 4 neurons in the hidden layer, one decision neuron, and output with a sigmoid activation function.

The number of hidden neurons was determined according to a commonly used rule, i.e., the square root of the sum of input and output neurons.

For the preliminary tests of diagnostic accuracy, 30 completed questionnaires were used: 20 from infected individuals and 10 from non-infected individuals. Photos of skin lesions were attached to 15 questionnaires, all from infected individuals. For 5 patients with confirmed infections, no photos of skin lesions were available, likely because the lesions were not observed, so the diagnosis was based solely on the questionnaire responses. Additionally, no photos were associated with the questionnaires from healthy individuals. Therefore, we

TABLE I

Result values.

Metrics	Formula	Values [%]
accuracy	$\frac{TP+TN}{TP+TN+FP+FN}$	93
recall	$\frac{TP}{TP+FN}$	100
precision	$\frac{TP}{TP+FP}$	91
specificity	$\frac{TN}{TN+FP}$	80
F1-score	$\frac{2 \times \text{precision} \times \text{recall}}{\text{precision} + \text{recall}}$	95

supplemented the questionnaires of 5 healthy patients with images of lesions that did not resemble Lyme disease.

It was then possible to study the operation of the decision-making system, in particular, the neural network that evaluated the survey results and the convolution network that classified the images. To assess the initial accuracy of the diagnosis, we used the classic leave-one-out method, which consists of training the system 30 times with 29 records and testing one not trained.

4. Discussion

As a result, 93% correct indications were obtained, with two incorrect ones belonging to the group of false positives. All of the above results are presented in the confusion matrix for the model in Fig. 7 and Table I, where: true positive (TP) refers to the number of instances where the model correctly identifies individuals as having Lyme disease when they actually have the disease; true negative (TN) refers to the instances where the model correctly identifies individuals as not having Lyme disease when they indeed do not have the disease; false positive (FP) refers to the instances where the model incorrectly identifies individuals as having Lyme disease when they actually do not have the disease; false negative (FN) refers to the instances where the model incorrectly identifies individuals as not having Lyme disease when they actually have the disease. As a result, 93% correct indications were obtained, with two incorrect ones belonging to the group of false positives. All of the above results are presented in the confusion matrix for the model in Fig. 7 and Table I, where: true positive (TP) refers to the number of instances where the model correctly identifies individuals as having Lyme disease when they actually have the disease; true negative (TN) refers to the instances where the model correctly identifies individuals as not having Lyme disease when they indeed do not have the disease; false positive (FP) refers to the instances where the model incorrectly identifies individuals as having Lyme disease when they actually do not have the disease; false negative (FN) refers to the instances where the model incorrectly identifies individuals as not having Lyme disease when they actually have the disease.

The high precision (91%) suggests a low rate of false positives (7%), while the high recall (100%) indicates effective detection of true positive cases — the system correctly recognized all infected cases. Perhaps they were so typical that they were easy to diagnose, but the system made a mistake only twice. A specificity of 80% suggests that the model performs well in identifying negative cases, but there is still a 20% risk of misclassification, which needs to be considered.

F1-score of 95% indicates a balance between precision and recall. This suggests that the model achieved accurate detection of Lyme disease while minimizing both false positives and false negatives.

5. Conclusions

The paper presents a telemedicine system designed to support Lyme disease diagnosis. From a technical standpoint, we evaluate the project positively as a working prototype.

The system test results, with diagnostic accuracy above 90% and 100% detection of infected individuals, can be considered at least good. False positive results are "safer" as they refer the patient to a doctor for further diagnosis or treatment. With a larger number of healthy individuals in the database, the specificity rate of 80% can be improved. The next step before any potential implementation should be gathering a larger dataset to further improve the results.

During the system's development, we established communication with the medical community in the Podlasie region and anticipated receiving data from new patients as they visited doctors. Additionally, it now seems feasible to integrate the application mentioned in the introduction into the decision-making system.

It is worth noting that the software and its underlying system could be used for diagnosing not only Lyme disease, but also other conditions where medical interviews and image analysis play a crucial role. A classic example would be childhood infectious diseases like measles, rubella, and scarlet fever, which often cause significant concern for parents, especially when access to a pediatrician is limited. Furthermore, translating the program into languages such as English and Ukrainian could broaden the target audience and increase the appeal of the application, expanding its potential user base significantly.

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