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Crowdsourcing Biological Specimen Identification

By Joseph R. Carvalko and Cara C. Morris

Consumer technology applied to health-care access.

EXISTING TECHNOLOGY MAY PROVIDE A SOLUTION TO THE intractable problem of the unmet demand in rural areas for the identification of biological specimens. The acquisition and transmission of biological specimens, revealed through low-cost microscopy, to a server would be viewed and analyzed by autonomous members of a crowdsource community, where, subject to a system of quality control, populations that do not have access to medical diagnostic facilities might have the full advantages of medical analyses. In our proposed system, a smartphone is equipped with a low-cost microscope interface. This enables health-care workers to obtain digital images of biological specimens, bacteria, or tissue cultures that are then transmitted to a cloud server. These image data can be made available, via crowd-sourcing, for experts to provide a consensus on the imaged specimen. The opinions of crowdsourced experts can be based in part on their scientific peer ranking and professional qualifications and in part on their history of contributions and peer ranking within the crowd-sourcing community. Different opinions as to the nature of the specimen provided can be weighed by the crowdsourcing software engine that then presents the conclusions to the originating health-care worker.

The analysis of biological specimens for the diagnosis of disease in

impoverished rural areas has proven intractable, mainly hampered by the cost of instruments and qualified staffing. However, an ultra-inexpensive microscope used with a smartphone has given rise to a proposed system where a health-care worker transmits the image of a specimen to a cloud server for examination by crowdsource volunteers, who, through consensus, form a diagnosis or specimen identification, which is communicated to the originator [1].

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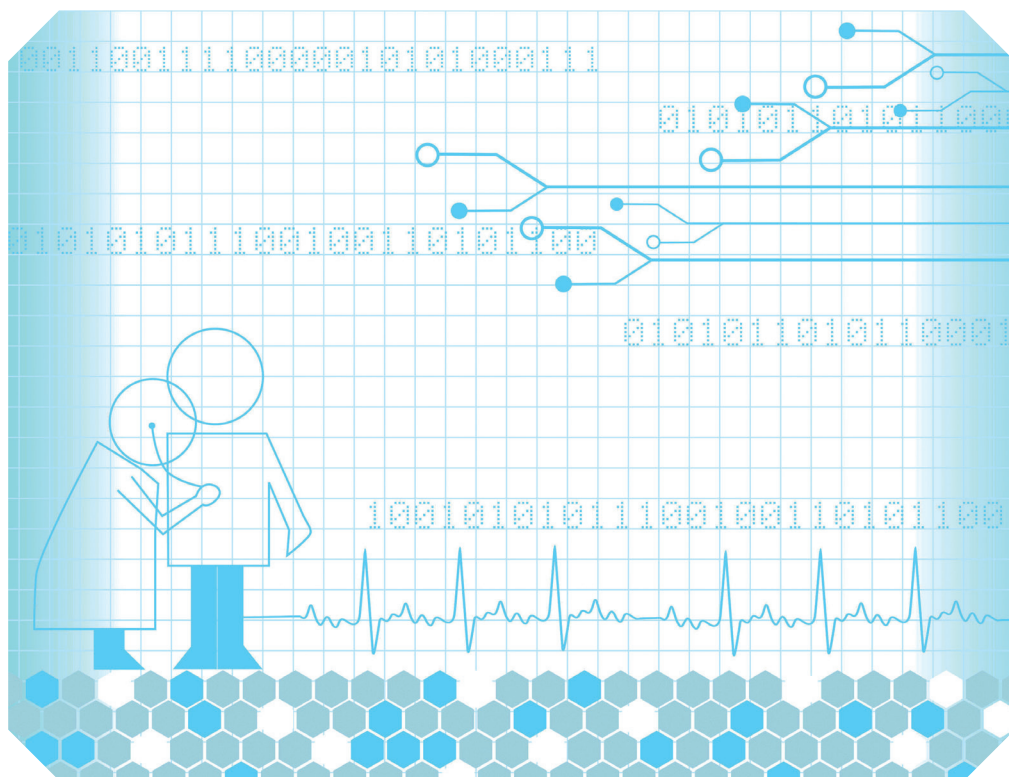


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potential for providing medical diagnosis for thousands of communities that lack basic health care. More than 1.5 billion people have access to some rudimentary health care; yet more than 4 billion others have none [2]. With the advent of smartphones and crowdsourcing, it may be possible to diagnose and then treat a range of critical illnesses in places currently lacking adequate medical facilities.

According to UNICEF, malaria affects 350–500 million people each year, killing upward of 700,000 million children in Africa. Many die because the routine identification of diseases proves too costly for small rural villages. Medical diagnosis accounts for about 10% of all medical costs, or approximately US\$250 billion per year in the United States alone [3]. Beyond economic costs, delays and inaccurate diagnoses often contribute to preventable human suffering and death.

The diseases observable through a simple microscope include foodborne [e.g., worms and fungi (molds)], parasites (including helminth eggs and larvae), waterborne (e.g., *Schistosoma mansoni*), bloodborne (HIV and *Plasmodium falciparum*), and emerging diseases (e.g., methicillin-resistant *Staphylococcus aureus*). The detection of cytological dysfunction through microscopy, for example, extant in red or white blood cells, often serves as a vital step in the diagnosis of diseases such as sickle cell anemia, leukemia, or the identification of microbial invasions.

Medical laboratories, even those with rudimentary equipment, such as a microscope, prove costly, especially factoring in the capital, training, and staffing. Reduced-cost alternatives exist for the detection of specific diseases. A case in point: a malaria test kit supplies a less costly option over microscopy. But many rural communities cannot afford either malaria test kits or microscopes. Overall, microscopes, although too expensive for poor communities, are more versatile than kits for disease-specific detection and remain the “gold standard test for the diagnosis of malaria” [4], [5].

Recently developed, paper-based, origami-like microscopes—the size of a bookmark and virtually indestructible—will soon be widely available at a cost well under US\$1. One print-and-fold microscope, coined Foldscope, can be assembled from a flat sheet of paper [6]. Reportedly, it can provide more than 2,000× magnification with submicron resolution (800 nm). Weighing fewer than 8.8 g and measuring $70 \times 20 \times 2 \text{ mm}^3$, it can fit in a pocket. Because it is a scalable design for application-specific projects instead of a general-purpose instrument, it is suitable for field-based citizen science.

Microscopes alone do not solve the problem of diagnosing illnesses in communities too poor to employ doctors or clinicians with pathology backgrounds. A link to where others might assist in diagnosis would help, provided resources were available in a timely manner.

Smartphones communicate image and text information, both of which are essential for a remote medical diagnostic system, i.e., one requiring the image of the specimen embodying the disease and patient information. A special lens can turn a smartphone into a portable handheld

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microscope (the current minimum camera requirements are 5 MP), e.g., a Foldscope-type microscope or, alternatively, as one such device maker claims, a soft lens that sticks directly onto the camera lens on the back of the phone and allows a user to zoom into 15× magnification (a 150× lens will become available shortly) [7]. Although still in the research stage, fluorescent microscopes that use a physical attachment to an ordinary cell phone will soon become available for identifying and tracking diseases such as tuberculosis and malaria [8]. Following the upload of an image of a microscopic specimen, there remains the task of diagnosis, which may be assisted through crowdsourcing.

THE DAWN OF CROWDSOURCED DIAGNOSIS

Wired magazine coined the term *crowdsourcing* in 2006 to describe the process of seeking a solution to a problem from a large community. One of the first medical crowdsourcing companies to offer diagnosis services is CrowdMed, a San Francisco-based health-care start-up, launched during the TEDMED 2013 conference held in Washington, D.C. It claims to diagnose medical cases more quickly than one’s physician and to offer individuals and insurance providers reduced health-care costs [9]. Its Web site reports that it has registered more than 200 active medical “detectives” that work in or study medicine. The detectives suggest diagnoses and “collectively vote” on the most likely ones, using a patented prediction technology that aggregates information and assigns a consensus-based probability to reach a determination [10].

Crowdsourcing might be thought of as a form of social computing, as that term refers to supporting computations carried out by groups, where the group has the potential to exhibit judgment exceeding that of any single member [11]. Surowiecki postulates that four criteria must be satisfied: 1) each person must have private information of known facts, 2) a crowd member opinion must not be determined by the opinions of others in the crowd, 3) a crowd member must be permitted to specialize and draw on local knowledge, and 4) a mechanism must exist for turning private judgments into collective judgments [12].

In an ideal ensemble of medically related decision makers, we might admit only expert participation into the activity. But a crowdsourced limited to trained pathologists is not feasible,



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especially when financial remuneration does not exist. In crowdsourcing, volunteers self-select or at least provide largely unverified qualifications for their inclusion in the group. Optimistically, a mission might draw upon reasonably qualified volunteers drawn from disparate biomedical occupations, perhaps including trained pathologists. What is not included among the Surowiecki criteria is the ability to assess a member's lack of knowledge or, more candidly, ineptitude in forming an opinion, essentially controlling what a member may not know, and which may bear on the integrity of the member's quality of judgment.

Crowdsourcing a biological specimen constrains volunteers to decide a classification, not in some absolute reductionist fashion but based on probability, often subjective, that when after considering all the evidence, the artifact under observation likely belongs in one class versus another. And as indicated, the error in classification may have its origins in the lack of a full appreciation of the significance of the evidence.

In a 1975 experiment in subjective probability, Capen polled more than 1,200 people who had been invited to estimate dates, values, and quantities about which they had some passing acquaintance but were not certain [13]. Each subject was asked a series of ten questions ranging from how many cars were registered in California in 1972 to the driving distance between Los Angeles and New Orleans. Individuals were asked to give ranges of estimates that supposedly included the true value, for example, to put a 90% confidence range on the year St. Augustine was settled by Spaniards. A response might set the range as 1,500–1,550, inferring only a 10% chance the city was settled before or after those dates.

Capen found 1), more than 350 participants had no idea how to describe uncertainty; 2) subjects who were uncertain about answers were unaware of the degree of their uncertainty; 3) most could not distinguish between a 30 and 98% confidence interval; 4) the more knowledge a subject had about a topic, the larger the chosen confidence interval; and 5) a universal tendency to understate the interval existed (i.e., an overestimate about the precision of one's knowledge). Any medical diagnosing system that relies on crowdsourcing needs to consider Capan's findings to minimize the levels of false positives and false negatives.

Although no systems currently utilize crowdsourcing methods for the identification of biological specimens, analogous solutions for improving the effectiveness of the diagnosis of an illness using a crowd fall into three categories: 1) testing/qualifying volunteers before accepting them into

the crowdsource community, 2) creating a database to compare patient symptoms, and 3) establishing rules to determine the quality of an identification of biological specimens.

As to solution 1), will testing discourage participation? This is an open question and one that should not be dismissed out of hand. However, the integrity of decisions by members of a crowdsourced community might be quality controlled in real time, as suggested by solutions 2) and 3), provided a system had measurement criteria that reflected an acceptable performance level.

Utilizing the U.S. Patent and Trademark Office site, three patent applications were found that dealt with crowdsourcing decisions falling into the second solution category. Each takes a different approach, but they collectively reveal a practical shortcoming in qualifying a decision based on rule setting.

Zziwa, in U.S. Patent Application 20,130,253,940, discloses collecting and storing electronic data for a user seeking to obtain a medical diagnosis by applying stored rules [14]. Experts create the rules, which are assigned a trust factor dependent on the opinions of the users (presumably the individual or health-care worker searching for a cure). Explicit rules may not lead to the effective identification of biological specimens, in part because classification depends on a complicated mix of morphology, color, texture, and other cytological features that make categorical rule sets impracticable in what remains largely heuristic, learned through education, training, and experience. In fact, the Zziwa-type solutions appear to counter Surowiecki's advice that a crowd opinion should be independent of others, and this would logically extend to user's opinions.

At least one patent disclosure assigns different weights to responses received from peers as opposed to a trust factor tied to a diagnosis, while another assigns a trust score to each member of the participating group, the trust score based on completion of a crowdsourcing activity to establish a level of trust earned. Neither patent application bases volunteer performance on the conformity to a peer consensus [15], [16].

A PROPOSAL FOR IMPROVED CREDENTIALING

We propose crowdsourcing medical biological identification by comparing the identification to a classification norm as established by others in the peer group. In this method, a processor assigns a weight to the identification based on prior observational accuracy of the volunteer. The system determines the weight as a function of a qualification of an individual, which includes two components: 1) education, training, experience, and years in the field of the biological or medical arts and 2) the number of times the individual on prior occasions selected an identification that agreed with the majority.

The system rank orders biological classification on the basis of a frequency of chosen occurrence. It then compares the crowdsource volunteer to the majority choice. If the crowdsource volunteer aligns with the majority, the system increments the crowdsource volunteer's credential, applying the increase to a subsequent biological classification or

diagnosis. If a volunteer was previously credited a weight of ten, the weight may be stepped up to 11 and applied the next time the volunteer engages in an analysis. Likewise, if the crowdsourced volunteer does not align with the most frequent diagnosis, the system decreases the volunteer's credit.

In summary, crowdsourcing judgment under the proposed method would draw upon a population of reasonably qualified volunteers from related fields (such as highly skilled pathologists, college biology students, nurses, and retired medical service personnel); collecting the opinions of the crowdsourced volunteers and weighting them based on qualifications and on the proximity of their biological classification or diagnosis to a mean peer assessment; forming a biological classification or diagnosis based on a statistical parameter, such as a weighted frequency of a diagnosis (mean peer diagnosis) occurring among the crowdsourced volunteers; and then transmitting the identification/diagnosis of the specimen to the caregiver, who may prescribe a drug, therapy, or medical test.

CONCLUSION

As we apply technology to improve health and extend lifespans, disparities in delivery persist, splitting the world into haves and have-nots. Undoubtedly, large populations that do not have access to the most rudimentary laboratory technology will exist for the foreseeable future; nevertheless, technologically sophisticated societies have a responsibility to deploy tools that might offer a quantum improvement in the well-being of underserved communities. Low-cost microscopy in combination with crowdsourced identification of biological specimens may prove to be a step in this direction.

ABOUT THE AUTHORS

Joseph R. Carvalko (carvalko@sbcglobal.net and Joseph.carvalko@quinnipiac.edu) earned his J.D. degree from the Quinnipiac University School of Law and his B.S. degree in electrical engineering as well as his M.F.A. degree (writing) from Fairfield University, Connecticut. He is an adjunct professor of law, science, and technology at Quinnipiac University School of Law. He is a member of the IEEE Society on Social Implications of Technology, the IEEE Engineering in Medicine and Biology Society, the American Bar Association Section of Science and Technology Law, the Yale Community Bioethics Forum of the Program on Biomedical Ethics at Yale School of Medicine, and the Yale Technology and Ethics working research group. He is admitted to practice law in Connecticut and New York and before the U.S. Patent and Trademark Office.

Cara C. Morris (tech4u2day@gmail.com) earned her J.D. degree from Suffolk University Law School and her B.A. degree in political science from Manhattanville College. She is a degree candidate in biotechnology at Palm Beach State College. She is a member of the American Bar Association Science and Technology Law and Intellectual Property Law Sections as well as the Florida Academy of Sciences. She is

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also a member of the IEEE Engineering in Medicine and Biology Society and the IEEE Society on Social Implications of Technology.

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