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Systems for automated preparation of biological specimens

Abstract

An automated system for processing a sample contained in a liquid sample container includes an automated tool head configured to rotate about a first axis, and to translate along a second axis different than the first axis, an analytic element positioner having an analytic element holder configured to releasably grip an analytic element, and a specimen transfer device carried by the tool head, wherein the tool head is configured to automatically position a working end of the specimen transfer device to obtain a specimen from a sample container held in the sample container holder, and to transfer the obtained specimen to an analytic element held by the analytic element holder, respectively, through one or both of rotation of the tool head about the first axis and translation of the tool head along the second axis.

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Background/Summary

RELATED APPLICATIONS DATA (1) The present application is a continuation of U.S. patent application Ser. No. 17/133,690, filed Dec. 24, 2020, now U.S. Pat. No. 11,536,634, which is a continuation of U.S. patent application Ser. No. 16/084,955, filed Sep. 13, 2018, now U.S. Pat. No. 10,900,875, which is a National Phase entry under 35 U.S.C § 371 of International Patent Application No. PCT/US2018/021879, filed Mar. 9, 2018, which claims priority to U.S. patent application Ser. No. 15/454,819, filed Mar. 9, 2017, now abandoned, the contents of which are incorporated by reference in their entirety into the present application.

FIELD
(1) The present disclosure generally relates to preparation of biological specimens, and more particularly, to automated systems and methods for collecting a biological specimen from a liquid sample container and dispensing the specimen onto an analytic element, such as a specimen slide, as well as automated systems and methods for obtaining an aliquot of the sample for additional testing.
BACKGROUND
(2) Cytology is a branch of biology dealing with the study of the formation, structure, and function of cells. As applied in a laboratory setting, cytologists, cytotechnologists, and other medical professionals make medical diagnoses of a patient's condition based on visual examination of a specimen of the patient's cells. A typical cytological technique is a “pap smear” test, in which cells are scraped from a woman's cervix and analyzed in order to detect the presence of abnormal cells, a precursor to the onset of cervical cancer. Cytological techniques are also used to detect abnormal cells and disease in other parts of the human body.
(3) Cytological techniques are widely employed because collection of cell samples for analysis is generally less invasive than traditional surgical pathological procedures such as biopsies, whereby a solid tissue specimen is excised from the patient using specialized biopsy needles having spring loaded translatable stylets, fixed cannulae, and the like. Cell samples may be obtained from the patient by a variety of techniques including, for example, by scraping or swabbing an area, or by using a needle to aspirate body liquids from the chest cavity, bladder, spinal canal, or other appropriate area. The acquired cell sample is typically placed in a preservative solution and subsequently extracted from the solution and transferred to a glass slide. A fixative is applied to the cell sample to ensure the cells remain in place on the glass slide for facilitating subsequent staining and examination.
(4) It is generally desirable that the cells on the slide have a proper spatial distribution, so that individual cells can be examined. A single layer of cells is typically preferred. Accordingly, preparing a specimen from a liquid sample containing many cells (e.g., tens of thousands) typically requires that the cells first be separated from each other by mechanical dispersion, liquidic shear, or other techniques so that a thin, monolayer of cells can be collected and deposited on the slide. In this manner, the cytotechnologist can more readily discern the presence of any abnormal cells in the patient sample. The cells are also able to be counted to ensure that an adequate number of cells have been evaluated.
(5) Certain methods and apparatus for generating a thin monolayer of cells and from a liquid sample container and then transferring this thin layer to a “specimen slide” that is advantageous for visual examination are disclosed in U.S. Pat. Nos. 5,143,627, 5,240,606, 5,269,918, 5,282,978,

6,562,299, 6,572,824 and 7,579,190, the disclosures of which are incorporated herein by reference in their entirety. According to one method disclosed in these patents, a patient's cells in a preservative liquid in a sample container are dispersed using a spinning sample collector disposed therein. A controlled vacuum is applied to the sample collector to draw the liquid through a screen filter thereof until a desired quantity and spatial distribution of cells is collected against the filter. Thereafter, the sample collector is removed from the sample container and the filter portion impressed against a glass slide to transfer the collected cells to the slide in substantially the same spatial distribution as collected. Apparatus manufactured according to the teachings of one or more of these patents have been commercially successful, such as the ThinPrep® 2000 Processor (specimen slides processed from patient samples one at a time), and the ThinPrep® 5000 Processor (specimen slides batch processed from patient samples), which are manufactured and sold by Hologic, Inc., located in Marlborough, Massachusetts. Further reference is made to U.S. Pat. Nos. 7,556,777, and 7,771,662, the disclosures of which are incorporated herein by reference in their entirety.

(6) Once a specimen slide has been prepared, the specimen may be visually inspected by a cytotechnologist, typically under magnification, and with or without various sources of illumination. Additionally, or alternatively, automated slide imaging systems are used to aid in the cytological inspection process. For example, an automated slide imaging system may capture an image of all, or substantially all, of the cells captured on the slide, and perform a preliminary assessment of the cells using image processing techniques in order to direct the cytotechnologist to potentially the most relevant cells on the slide for close inspection. Examples of such imaging systems are disclosed in U.S. Pat. Nos. 7,587,078, 6,665,060, 7,006,674 and 7,590,492, the disclosures of which are incorporated herein by reference in their entirety. Whether by inspection of the actual specimen slide under magnification, or of magnified images of the specimen, the specimen is typically classified by the cytotechnologist as either “normal” or “abnormal,” wherein an abnormal sample normally falls in one of the major categories defined by The Bethesda System for Reporting Cervical/Vaginal Cytologic Diagnosis, which categories include Low-Grade Squamous Intraepithelial Lesions (LSIL), High-Grade Squamous Intraepithelial Lesions (HSIL), Squamous Cell Carcinoma, Adenocarcinoma, Atypical Glandular cells of Undetermined Significance (AGUS), Adenocarcinoma in situ (AIS), and Atypical Squamous Cell (ASC). Additional information regarding cell specimen classifications is widely available.

(7) It may be desirable to perform other types of diagnostic testing of the same patient sample, such as for Human Papilloma Virus (HPV). Based on the strong correlation between HPV and cervical cancer, it has been recommended that HPV DNA testing be used as a triage test for patients whose Pap smear results are classified as ASC-US. In the case where a liquid-based Pap smear has been performed, the same sample used to perform the Pap smear analysis can be conveniently used to perform a “reflexive” HPV DNA test, thereby obviating the need for a repeat clinic visit and second Pap smear. For example, if a specimen is classified as positive for ASC-US, an “aliquot” (e.g., 4 mL) of the liquid sample may be removed from the stored vial and sent to a molecular diagnostic laboratory for HPV DNA testing.

(8) Significantly, laboratories that perform HPV DNA tests are weary of molecular contamination, a well-known problem in molecular diagnostic laboratories. Thus, due to the risk of cross-contamination, molecular diagnostic laboratories may not accept aliquots that have been taken from an already processed liquid-based Pap smear for fear of unnecessarily generating false HPV positives. As such, it is desirable to obtain and store an aliquot of each patient sample prior to the specimen slide making process in order to preserve a portion of the sample without exposure to cross-contamination. By way of example, certain methods and apparatus for obtaining an aliquot of a patient sample prior to the specimen slide making process are disclosed in U.S. Pat. Nos. 7,674,434, and 8,137,289, the disclosures of which are incorporated herein by reference in their entirety. Additional examples of obtaining sample aliquots in general but not necessarily in

conjunction with making specimen slides are disclosed in U.S. Pat. No. 9,335,336 and U.S. Pat. Publ. No. 2017/0052205, the disclosures of which are incorporated herein by reference in their entirety.

(9) Besides being used for HPV DNA testing, aliquots from liquid-based Pap smear samples can also be used DNA testing for other sexually transmitted diseases, such as *Chlamydia trachomatis* and *Neisseria gonorrhoeae*. However, false positives are a special problem when testing for *Chlamydia trachomatis* and *Neisseria gonorrhoeae*, because they could have enormous family and social repercussions. Thus, molecular diagnostic laboratories are even more reluctant to accept aliquots from already processed liquid-based Pap smear samples. Testing for other sexually transmitted diseases need not be used only to triage ASC-US specimens. Indeed, such testing is intended to be performed in parallel to the Pap smear tests at the request of the physician, aliquots may be taken from the Pap smear samples prior to processing, e.g., by manually pipetting the aliquot from the vial, thereby minimizing the risk of cross-contamination. However, this step may still not satisfy the strict contamination prevention requirements imposed by molecular diagnostic laboratories.

(10) In addition to contamination issues, the pipetting of an aliquot from a liquid-based Pap smear sample, whether done before or after the sample is processed, and whether done for HPV testing or testing of any other sexually transmitted disease, increases cost in the form of manual labor which involves not only pipetting the aliquot into an extra vial, but also labeling the vial.

(11) There thus is a need to provide improved apparatus and methods for obtaining an aliquot from a liquid-based biological sample, such as a Pap smear sample while minimizing the risk of cross-contamination.

SUMMARY

(12) Embodiments of the present disclosure are directed to improved automated systems and methods for processing a sample (such as a biological sample) contained in a sample container.

(13) In one embodiment, an automated system for processing a sample contained in a liquid sample container includes a sample container holder configured for holding a sample container and an automated tool head configured to rotate about a first axis, and to translate along a second axis different than the first axis, the system further including a specimen transfer device carried by the tool head, wherein the tool head is configured to automatically position a working end of the specimen transfer device to obtain a specimen from a sample container held in the sample container holder, and then to transfer the obtained specimen to an analytic element (e.g., a slide) held in an analytic element holder, respectively, through one or both of rotation of the tool head about the first axis and translation of the tool head along the second axis. Without limitation, the working end of the specimen transfer device may be configured to receive a filter thereon, the filter comprising a tubular body that forms a seal with the working end portion of the specimen transfer device and a porous membrane end portion that is configured to allow liquid to pass therethrough while retaining cellular matter on an outer surface thereof.

(14) The system may further include an analytic element positioner including the analytic element holder, wherein the analytic element holder is configured to releasably grip the analytic element. The analytic element positioner may be configured to automatically place an analytic element carried by the analytic element positioner into a fixative container held in the fixative container holder after a specimen has been transferred onto the analytic element. The system may include an analytic element (e.g., slide) loading platform located on a surface of the tool head, wherein the analytic element positioner operatively cooperates with the tool head so that the analytic element holder automatically engages and removes an analytic element placed on the loading platform, and wherein the analytic element positioner operatively cooperates with the tool head to automatically position an engaged analytic element proximate the working end of the specimen transfer device to transfer the specimen onto the engaged analytic element.

(15) The system may further include a sample container capping device disposed on the tool head

and configured to controllably grip and release a cap of a sample container held in the sample container holder, wherein the tool head is configured to automatically position the sample container capping device proximate the sample container cap through one or both of rotation of the tool head about the first axis and translation of the tool head along the second axis, and wherein the sample container capping device operatively cooperates with the sample container holder to remove or install the sample container cap. Without limitation, the sample container holder may be configured to automatically rotate in one of a clockwise rotational direction and a counter-clockwise rotational direction while the sample container capping device engages the sample container cap in order to remove the sample container cap from the sample container, and wherein the sample container holder is configured to automatically rotate in the other one of the clockwise rotational direction and the counter-clockwise rotational direction while the sample container capping device engages the sample container cap in order to install the sample container cap onto the sample container.

(16) The system may further include a pipette tip dispenser and a pipettor carried by the tool head, the pipettor having a pipette tip engaging member configured to releasably engage pipette tips, wherein the tool head is configured to automatically position the pipette tip engaging member proximate the pipette tip dispenser to allow the pipette tip engaging member to engage a pipette tip held by the pipette tip dispenser through one or both of rotation of the tool head about the first axis and translation of the tool head along the second axis. Without limitation, the pipette tip dispenser may be mounted on a pipette tip dispenser transporter configured to translate the pipette tip dispenser relative to the tool head so that the pipette tip dispenser may be selectively translated to a location at which the tool head positions the pipette tip engaging member to engage a pipette tip from the pipette tip dispenser. The system may further include a pipette tip dispenser isolation chamber, wherein the pipette tip dispenser transporter is configured to selectively translate the pipette tip dispenser between the location at which the tool head positions the pipette tip engaging member to engage a pipette tip from the pipette tip dispenser and a second location within the isolation chamber. A pipette tip waste bin may be mounted on the pipette tip dispenser transporter, wherein the pipette tip dispenser transporter is configured to selectively translate the pipette tip waste bin to a location at which the tool head positions the pipette tip engaging member to disengage a pipette tip into the pipette tip waste bin. For example, the pipette tip waste bin may be mounted on the pipette tip transporter relative to the pipette tip dispenser such that, when the pipette tip waste bin is translated to the location at which the tool head positions the pipette tip engaging member to disengage a pipette tip into the pipette tip waste bin, the pipette tip dispenser is simultaneously translated into the isolation chamber.

(17) In embodiments including the pipettor, the system may further include a supplemental container holder configured for holding a supplemental container, wherein the tool head is configured to automatically position the pipette tip engaging member into a position in which a pipette tip engaged on the pipette tip engaging member is inserted into a sample container held in the sample container holder, and into a position in which the engaged pipette tip is inserted into a supplemental container held in the supplemental container holder, respectively, through one or both of rotation of the tool head about the first axis and translation of the tool head along the second axis. The supplemental container may be an aliquot container, wherein when the tool head and pipettor operatively cooperate to automatically cause the pipette tip engaging member to engage a pipette tip from the pipette tip dispenser, draw an aliquot of a sample from a sample container held in the sample container holder using the engaged pipette tip, and dispense the obtained sample aliquot into the aliquot container, respectively. Alternatively, and without limitation, the supplemental container may be a reagent container containing a reagent, and wherein when the tool head and pipettor operatively cooperate to automatically cause the pipette tip engaging member to engage a pipette tip from the pipette tip dispenser, draw an aliquot of reagent from the reagent container using the engaged pipette tip, and dispense the reagent aliquot into a sample container held in the sample container holder, respectively.

(18) A supplemental container capping device may be disposed on the tool head and configured to controllably grip and release a cap of a supplemental container held in the supplemental container holder, wherein the tool head is configured to automatically position the supplement container capping device proximate the supplemental container cap through one or both of rotation of the tool head about the first axis and translation of the tool head along the second axis, and wherein the supplement container capping device operatively cooperates with the supplemental container holder to remove or install the supplemental container cap. For example, the supplemental container holder may be configured to automatically rotate in one of a clockwise rotational direction and a counter-clockwise rotational direction while the supplement container capping device engages the supplemental container cap in order to remove the supplemental container cap from the supplemental container, and wherein the supplemental container holder is configured to automatically rotate in the other one of the clockwise rotational direction and the counter-clockwise rotational direction while the supplement container capping device engages the supplemental container cap in order to install the supplemental container cap onto the supplemental container. In some embodiments including both a sample container capping device and a supplemental container capping device, the two capping devices may be offset from one another on the tool head such that, when the sample container capping device is in a position to grip and remove the sample container cap, the supplemental container capping device is in a position to grip and remove the supplemental container cap without further rotational movement of the head tool.
(19) The system may further include an analytic element (e.g., slide) loading platform located on a surface of the tool head, wherein the analytic element positioner operatively cooperates with the tool head so that the analytic element holder automatically engages and removes an analytic element placed on the loading platform, and wherein the analytic element positioner operatively cooperates with the tool head to automatically position an engaged analytic element proximate the working end of the specimen transfer device to transfer the specimen onto the engaged analytic element.
(20) The system may further include a reader (e.g., a bar code reader or scanner) positioned on the tool head and configured for reading sample container indicia located any of a sample container. An analytic element printer may be provided in communication with reader and configured for printing analytic element indicia corresponding to sample container indicia read by the reader onto an analytic element, which may be, without limitation, a slide. An aliquot container printer may also be provided in communication with the reader and configured for printing analytic element indicia corresponding to sample container indicia read by the reader onto an aliquot container. In various embodiments, the reader is further configured to read indicia on other system components and consumables, such as on a slide or on a filter used for obtaining a sample specimen.
(21) Embodiments of the system may include a controller for controlling operation of one or more of the tool head, pipettor, capping devices, and analytic element positioner, as well as a user interface operatively coupled with the controller and configured for displaying system status and/or inquires to a system operator, and for receiving user inputs in response to the displayed system status and/or inquires.
(22) In one embodiment, an automated system for processing a sample contained in a liquid sample container includes a sample container holder configured for holding a sample container, an automated tool head configured to rotate about a first axis, and to translate along a second axis different than the first axis, a pipette tip dispenser, a pipettor carried by the tool head, the pipettor having a pipette tip engaging member configured to releasably engage pipette tips, wherein the tool head is configured to automatically position the pipette tip engaging member proximate the pipette tip dispenser to allow the pipette tip engaging member to engage a pipette tip held by the pipette tip dispenser through one or both of rotation of the tool head about the first axis and translation of the tool head along the second axis, wherein the pipette tip dispenser is mounted on a pipette tip dispenser transporter configured to translate the pipette tip dispenser relative to the tool head so

that the pipette tip dispenser may be selectively translated to a location at which the tool head positions the pipette tip engaging member to engage a pipette tip from the pipette tip dispenser; and a pipette tip dispenser isolation chamber, wherein the pipette tip dispenser transporter is configured to selectively translate the pipette tip dispenser between the location at which the tool head positions the pipette tip engaging member to engage a pipette tip from the pipette tip dispenser and a second location within the isolation chamber.

(23) In yet another embodiment, an automated system for processing a sample contained in a liquid sample container includes sample container holder configured for holding a sample container, an automated tool head configured to rotate about a first axis, and to translate along a second axis different than the first axis, a pipette tip dispenser, a pipettor carried by the tool head, the pipettor having a pipette tip engaging member configured to releasably engage pipette tips, wherein the tool head is configured to automatically position the pipette tip engaging member proximate the pipette tip dispenser to allow the pipette tip engaging member to engage a pipette tip held by the pipette tip dispenser through one or both of rotation of the tool head about the first axis and translation of the tool head along the second axis, and a supplemental container holder configured for holding a supplemental container, wherein the tool head is configured to automatically position the pipette tip engaging member into a position in which an engaged pipette tip is inserted into a sample container held in the sample container holder, and into a position in which an engaged pipette tip is inserted into a supplemental container held in the supplemental container holder, respectively, through one or both of rotation of the tool head about the first axis and translation of the tool head along the second axis. Without limitation, the supplemental container may be one of a reagent container and an aliquot container.

(24) In still another embodiment, a system for processing a sample contained in a liquid sample container includes a sample container holder configured for holding a sample container, a supplemental container holder configured for holding a supplement container, an automated tool head configured to rotate about a first axis, and to translate along a second axis different than the first axis, a first capping device disposed on the tool head and configured to controllably grip and release a cap of a sample container held in the sample container holder, wherein the tool head is configured to automatically position the first capping device proximate the sample container cap through one or both of rotation of the tool head about the first axis and translation of the tool head along the second axis, and wherein the first capping device operatively cooperates with the sample container holder to remove or install the sample container cap, and a second capping device disposed on the tool head and configured to controllably grip and release a cap of a supplemental container held in the supplemental container holder, wherein the tool head is configured to automatically position the second capping device proximate the supplemental container cap through one or both of rotation of the tool head about the first axis and translation of the tool head along the second axis, and wherein the second capping device operatively cooperates with the supplemental container holder to remove or install the supplemental container cap. The sample container holder may be configured to automatically rotate in one of a clockwise rotational direction and a counter-clockwise rotational direction while the first capping device engages the sample container cap in order to remove the sample container cap from the sample container, and wherein the sample container holder is configured to automatically rotate in the other one of the clockwise rotational direction and the counter-clockwise rotational direction while the second capping device engages the sample container cap in order to install the sample container cap onto the sample container. The supplemental container holder is configured to automatically rotate in one of a clockwise rotational direction and a counter-clockwise rotational direction while the second capping device engages the supplemental container cap in order to remove the supplemental container cap from the supplemental container, and wherein the supplemental container holder is configured to automatically rotate in the other one of the clockwise rotational direction and the counter-clockwise rotational direction while the second capping device engages the supplemental

container cap in order to install the supplemental container cap onto the supplemental container. The sample capping device and the supplemental capping devices may be offset from one another on the tool head such that, when the sample capping device is in a position to grip and remove the sample container cap, the supplemental capping device is in a position to grip and remove the supplemental container cap without further rotational movement of the head tool. Without limitation, the supplemental container is one of a reagent container and an aliquot container.
(25) Other and further aspects and features of the disclosed embodiments will become apparent in view of the following detailed description to be read in conjunction with the accompanying figures.

Description

BRIEF DESCRIPTION OF THE DRAWINGS
(1) The foregoing and other aspects of embodiments of the present disclosure are described in further detail with reference to the accompanying drawings, wherein like reference numerals refer to like elements and the description for like elements shall be applicable for all described embodiments wherever relevant, and in which:
(2) FIG. **1** is a right, front, perspective view of an exemplary automated biological sample processing system, according to one embodiment, including a sample processing cabinet, a slide printer, and an aliquot container printer;
(3) FIG. **2** is a right, front, perspective view of the sample processing cabinet of FIG. **1**, wherein the exterior cabinet walls are not shown in order to better show the system components located therein;
(4) FIG. **3** is a left, front, perspective view of the sample processing cabinet of FIG. **1**, wherein the exterior, and some interior, walls and/or partitions are not shown in order to better show the system components located therein;
(5) FIGS. **4-14** are respective left, right and front perspective views of the system components of the sample processing cabinet of FIG. **1**, illustrating the various movements and operations performed by the system components during a sample processing procedure;
(6) FIG. **15** is an elevated side perspective view of the components carried by a rotating tool head within the sample processing cabinet of FIG. **1**, in which the covering of the tool is not shown;
(7) FIG. **16** is a perspective view of the bottom of the sample processing cabinet of FIG. **1**, in which a bottom cover plate is removed to reveal the system components; and
(8) FIG. **17** is a perspective view of the back of the sample processing cabinet of FIG. **1**, in which a bottom cover plate is removed to reveal the system components.
DETAILED DESCRIPTION
(9) For purposes of illustration, the disclosed systems and methods of use described herein and illustrated in the accompanying figures are directed to the processing of a patient sample to produce a traditional cytological specimen slide, it will be appreciated that alternative embodiments may include the preparation of different types of biological specimens that are presented on differing types of analytic elements (i.e., other than cytological and other than on a slide) are contemplated within the scope of the disclosed embodiments and claims. Moreover, the disclosed systems and methods may be used for processing other types of liquid samples, including non-biological particulates and liquids. Thus, is should be understood that the disclosed and illustrated embodiments are presented for purposes of illustration and not limitation.
(10) As used herein, terms such “specimen”, “specimen sample”, “biological sample”, “cytological specimen”, “cell sample” and “biological specimen” may be used interchangeably and should be similarly understood and construed, unless the context of their use requires a more specific meaning. Additionally, terms such as “aliquot” and “aliquot sample” may be used interchangeably and should be similarly understood and construed. For example, and without limitation, the systems and methods disclosed herein may be used to process a biological sample contained in a

liquid sample container to produce a specimen or a specimen sample, as well as an aliquot or an aliquot sample. Moreover, the term “aliquot” is not to be construed as limiting, as an “aliquot” is another way of expressing “liquid sample” or a “portion of a liquid sample.” In other words, to obtain an aliquot or an aliquot sample of a biological sample means to obtain and store a portion of the original sample in a separate container for subsequent evaluation. Additionally, terms such as “sample container”, “liquid sample container”, “patient container” “sample vial” and “patient vial”, “tube” “supplemental container” and other permutations may be used interchangeably and should be similarly understood and construed, unless the context of their use requires a more specific meaning; for example, based on the stated contents of the container.
(11) As used herein, the terms “automatically” and “automated” mean that a system, apparatus, process and/or function is performed without user (e.g., system operator) intervention, often but not necessarily under the control of a programmed processor. In particular, the automated systems and methods disclosed herein advantageously reduce the number of manual steps required to prepare a biological sample, for example, the prepare a cytological specimen slide and/or to obtain an aliquot of a patient sample for additional testing and/or additional sample processing, such as introducing a reagent into a sample prior to further processing.
(12) FIG. **1** illustrates an exemplary automated biological sample processing system **10** that may be used for preparing a cytological specimen slide and/or an aliquot sample from a biological sample (e.g., obtained from a pap smear) contained in a liquid sample container. As will be explained in greater detail below, the system **10** may be used for additional types of sample processing, such as (without limitation) for adding a reagent to a biological or other type of sample.
(13) The system **10** generally includes a sample processing cabinet **11**, a slide printer **13** and an aliquot tube printer **19**. In the illustrated embodiment, the main components of the system **10** are housed in (and/or attached to) a sample processing cabinet **11**. As will be further described below, a slide printer **13** and aliquot tube printer **15** are operatively coupled with the sample processing cabinet via known wireless or wired communication connections (not shown) under the control of one or more processors located in the sample processing cabinet **11**. For simplicity, the one or more processors are hereinafter referred to collectively as a “system controller **60**” (further described below in conjunction with FIG. **17**) that controls the automated movements and other operations of the components of the system **10** housed within the sample processing cabinet **11**, as well as the communications with the respective slide printer **13** and aliquot vial printer **19**. For further ease in describing the system **10**, the components of the respective sample processing cabinet **11**, slide printer **13** and aliquot tube printer **19** are referred to collectively as “the system” **10**, without regard to where the specific components may be housed. It should be appreciated that, in alternate embodiments, the various components of the system **10** may be housed or otherwise provided separately.
(14) By way of examples, and without limitation, the system **10** may be configured to process sample containers, such as the Thin Prep® sample vial, and aliquot containers such as the Aptima® vial, which are both available from Hologic, Inc., Marlborough, Massachusetts (www.hologic.com).
(15) The sample processing cabinet **11** is preferably an environmentally enclosed housing (or “skin”) in order to reduce possible contamination introduced from the surrounding environment. In the illustrated embodiment, the sample processing cabinet **11** is provided with an openable front door **15** to provide access to the system components therein. The door **15** is hinged such that it swings open and closed and is provided with a handle **29**. In alternative embodiments, the door **15** may be a sliding door, e.g., which slides laterally to open and close. In the illustrated embodiment, the front door **15** has a transparent or semi-transparent panel so that the system components housed in the sample processing cabinet **11** are visible with the front door **15** in the closed position, although this is not a requirement for practicing the disclosed embodiments. With brief reference also to FIG. **16**, a stabilizing foot **79** that may be made of a material to minimize vibrational

movement of the cabinet may be provided at each of the four corners of the bottom, wherein the cabinet would typically rest on the four feet on a table top in a laboratory. The feet **79** are preferably sized and configured to allow for some clearance from the table surface, in addition to providing better stability.

(16) The slide printer **13** may be any commercially available slide printer, such as the Signature Slide Printer available from Primera, Technology, Inc., located in Plymouth, Minnesota (https://www.primera.com/signature-slide-printer). The slide printer **13** is loaded with new slides, and outputs printed slides through an output slot **17** that is be used for receiving a cytological specimen thereon as part of the processing of a respective patient sample container. In particular, the printer **13** prints indicia (e.g., a bar code) onto a portion of the slide that is to the side of where the cytological specimen is applied, wherein the printed indicia on the slide that matches or otherwise corresponds to indicia read on the sample container being processed, as explained in further detail below.

(17) The aliquot container printer **19** is preferably the same as taught in U.S. Pat. No. 9,724,948 (the '948 patent), the disclosure of which is incorporated herein by reference in its entirety. As explained by the '948 patent, the aliquot container printer **19** is provided with an opening **21** into which a new (unprinted) aliquot is inserted. The printer **19** prints indicia (e.g., a bar code) on the aliquot container that matches or otherwise corresponds to the indicia read on the sample container being processed, as explained in further detail below. The printed container is then ejected out of, or otherwise available for retrieval from, the opening **21**.

(18) FIGS. **2** and **3** depict the components of the system **10** that are housed within or otherwise attached to the sample processing cabinet **11**, wherein the cabinet housing walls are removed for ease in illustration. The cabinet **11** comprises a chassis **14** which may include a plurality of floors, walls, and/or supports that provide a primary support structure to which the various system components are installed/mounted.

(19) As best seen in FIG. **3**, a cylindrical sample container holder **16** is disposed in a lower central portion of the chassis **14**. As will be described in greater detail below, the sample container holder **16** is fixedly mounted on a rotating platform configured to rotate a sample container **12** (shown in FIG. **4**) held in the sample container holder **16** about a center z-axis of the container **12** for mixing the sample for achieving a substantially uniform dispersion of the cellular or other particular material contained in the sample container **12** prior to initiation of the processing thereof, and also to facilitate the uncapping and re-capping of the container **12** during the processing. In the illustrated embodiment, the sample container holder **16** is a cylindrical receptacle configured to snuggly receive and hold the sample container **12**. The sample container holder **16** has an outer wall that extends to a height less than the height of the sample container **12** such that a cap **43** on a sample container held in the sample container holder **16** is completely exposed. in order to facilitate the respective mixing, uncapping and capping thereof. In alternate embodiments, the sample container holder **16** may be any suitable shape for receiving the particular sample container being utilized with the system **10**, such as a rectangular box or other shape.

(20) As also best seen in FIG. **3**, an aliquot container holder **18** is disposed in a lower central portion of the chassis **14** directly in front of the sample container holder **16**. As will be described in greater detail below, the aliquot container holder **18** is fixedly mounted on a rotating platform configured to rotate an aliquot container **20** (shown in FIG. **5**) held in the aliquot container holder **18** about a center z-axis of the container **20** to facilitate the uncapping and re-capping of the container **20** during the sample processing. The aliquot container holder **18** is configured to snuggly receive and hold the aliquot container **20** and has an outer wall that extends to a height less than the height of the aliquot container **20** such that a cap **45** on the aliquot container **20** held in the aliquot container holder **18** is completely exposed in order to facilitate the respective mixing, uncapping and capping thereof. In the illustrated embodiment, the aliquot container holder **18** is sized and configured to hold a more tubular shaped container than that held by the sample container

holder **16**. In alternate embodiments, the aliquot container holder may be any suitable shape for receiving the particular aliquot container being utilized with the system **10**, such as a rectangular box or other shape. As is also described below, the system **10** may be used to for additional sample processing steps, such as for introducing a reagent into the sample container. As such, it should be understood that reference to the aliquot container holder **18** and the aliquot container **20** itself should be understood to be exemplary and not limiting. For example, the term “supplemental container holder” and “supplemental container” may be used interchangeably with aliquot container holder and aliquot container.

(21) More particularly, the sample container holder **16** and aliquot container holder **18** are each mounted on (or otherwise integrally formed with) respective underlying rotatable platforms (not shown) that are rotatably coupled to or near a floor of the chassis **14**. The respective rotating platforms, and thus the container holders **16** and **18**, may be selectively rotated about a center z-axis of each holder **16** and **18** in a clockwise rotational-direction or a counter-clockwise rotational direction. In particular, and with additional reference to FIG. **16**, a sample dispersion drive assembly is provided for performing relatively high-speed mixing of the contents of a sample container **12** held in the sample container holder **16** in order to disperse the cellular and/or other particulate matter suspended within the liquid sample prior to further processing of the sample. The sample dispersion rotational drive assembly includes a sample dispersion motor (not seen) mounted proximate a floor of the chassis **14**, the sample dispersion motor having a rotating output shaft that extends through the chassis floor to rotate a drive wheel **81**. The drive wheel **81** in turn rotates a larger diameter drive wheel **93** via a drive belt **88**. A hi/lo speed clutch **82** is operatively coupled with drive wheel **93** to selectively engage the drive wheel **93** with the respective rotating platform associated with the sample container holder **16** via a rotating drive shaft (not shown) extending back up through the chassis floor, to thereby also rotate the sample container holder **16** for performing relatively high-speed dispersion of the particles contained in a sample container **12** heled therein prior to further processing of the sample.

(22) With continued additional reference to FIG. **15**, the system **10** further includes a capping drive assembly for providing simultaneous relatively low-speed rotation of both the sample and aliquot container holders, **16** and **18**, for removing and reinstalling respective caps, **43** and **45**, on sample and aliquot containers, **12** and **20**, held in the respective sample and aliquot container holders, **16** and **18**, as is described below in greater detail. The capping drive assembly includes a capper motor **39** (seen in FIG. **3**) mounted on or near the floor of the chassis **14** in a lower side compartment **28** of the cabinet **11**. The capper motor is reversible in order to provide rotational motion in each of a clockwise direction and counter-clockwise direction. The capper motor **39** has a rotating output shaft that extends through a floor of the chassis **14** to rotate a drive gear **84**, which in turn rotates a larger drive gear **91** via a drive belt **85**. The hi/lo speed clutch **82** is operatively coupled with the drive gear **91** to thereby selectively engage the drive gear **91** with the rotating platforms associated with the sample container holder **16** and aliquot container holder **18** via a rotating shaft (not shown) that extends from the drive gear **91** back up through the chassis floor. Notably, a further arrangement of one or more drive gears/wheels and belts (not shown) are provided in a lower portion of the chassis, underlying the respective rotating platforms of the sample container holder **16** and aliquot container holder **18** in order to simultaneously distribute the rotational motion of wheel **91** to each of the rotating platforms. In this manner, actuating of the capping motor simultaneously rotates the sample container holder **16** and the aliquot container holder **18** at a relatively low-speed for removing or reinstalling the caps **43** and **45**, depending on the rotational direction of the output shaft of the motor **39**.

(23) Referring to FIG. **4**, the system **10** includes an automated tool head **30** that is rotatably mounted on a load bearing shaft assembly **34**, such that the tool head **30** is configured to pivot or rotate back and forth about a rotational axis, indicated by dashed line **33** in FIG. **7**. Preferably, the tool head **30** has a range of rotation through an arc of at least 270 degrees about the rotational axis,

although no specific minimum amount of rotational travel s is required beyond that necessary to perform the functions of the particular system embodiment. In the illustrated embodiment, the tool head rotates at least 270 degrees about its rotational the axis **33**. The load bearing shaft assembly **34** preferably includes spin bearings (not shown) to minimize friction between the tool head **30** and a mounting shaft (not shown) on which the tool head **30**. A tool head rotational actuating motor **36** is attached to the load bearing shaft assembly **34**, wherein an output shaft (not seen) of the motor **36** is operatively coupled to the shaft in or to rotate the tool head **30** via a drive belt **74**. The rotational actuating motor **36** is reversible to selectively provide rotational motion of the tool head **30** in both a clockwise rotational direction and a counter-clockwise rotational direction.

(24) With continued reference to FIG. **4**, the motor **36** is housed in a block-type support housing (also referred to as item **36** in the figures), which is threadably mounted on a vertical lead screw **55** (best seen in FIG. **15**) disposed in a rear portion of the chassis **14**. The lead screw **55** is actuated by a tool head linear actuating motor **32** mounted to a rear wall (near the top) of the chassis **14**. The tool head linear actuating motor **32** is reversible to selectively provide rotational motion of the lead screw **55** in both a clockwise rotational direction and a counter-clockwise rotational direction. In particular, rotation of the lead screw **55** in one of the clockwise rotational direction and a counter-clockwise rotational directions causes the motor block **36**, and thus the respective load bearing shaft assembly **34** tool head **30**, to travel linearly upward relative to the chassis **14** along a vertical (or “z”) translational axis indicated by dashed line **51** in FIG. **4**, and rotation of the lead screw **55** in the other one of the clockwise rotational direction and a counter-clockwise rotational directions causes the motor block **36**, and thus the respective load bearing shaft assembly **34** tool head **30**, to travel linearly downward relative to the chassis **14** along the vertical axis **51**. With this mechanical arrangement, and as further described below, the automated tool head **30** is configured to selectively controllably rotate in each of a clockwise rotational direction and a counter-clockwise rotational direction about the rotational axis **33**, and to independently selectively translate up or down along the vertical axis **51**, respectively, including simultaneous rotational and translational motion. Operation of the rotational actuating motor **36** controls the rotational position of the tool head **30** about the rotational axis **33**, and operation of the linear actuating motor **32** controls the vertical position of the tool head **30** along the vertical axis **51** within the interior of the cabinet **11**.

(25) A number of sample processing devices (or “tools”) are disposed circumferentially about the tool head **30**, and are arranged so that the respective function accomplished by each of the devices may be accomplished by one or both of one or both of rotation of the tool head about its rotational axis **33** and translation of the tool head **30** along its vertical translation axis **51**, without requiring movement of the tool head **30** in an x direction (i.e., sideways relative to the cabinet **11**), or a y direction (i.e., back to front relative to the cabinet **11**). In the illustrated embodiment, these devices include an indicia reader **31** configured to read an indicia such as a bar code on the sample container **12**; a first capping device **42** including pneumatically controlled grippers configured for releasably griping a cap **43** of a sample container **12** being processed; a second capping device **44** including pneumatically controlled grippers configured for releasably griping a cap **45** of a supplemental container **20** (e.g., an aliquot tube or a vessel containing a reagent); a pipettor **37** (best seen in FIG. **15**) having a pipette tip engaging member **38** extending outwardly from the tool head **30** and configured for releasably engaging pipette tips; a specimen collection and transfer device (hereinafter “specimen transfer device”) **40** having a working end extending outwardly from the tool head **30** and configured for obtaining a specimen sample from the sample container; and a slide loading bed or “platform” **46** configured to receive a slide **50** to be delivered by the tool head **30** to a slide holder **57** of a slide positioner assembly **56** (as described below in greater detail).

(26) Each of devices **31**, **42**, **44**, **37**/**38**, **40** and **46** is located on the tool head **30** a different circumferential and/or angular position and orientation about the rotational axis **33**, so as to that each of these devices rotate with the tool head **30** as the tool head is rotated about its rotational axis **33** under control of the rotational actuating motor **34**, and are moved vertically up or down within

the interior of the cabinet **11** along vertical axis **51** of the tool head under control of the translational actuating motor **32**. Thus, the rotational and/or vertical translational actuation of the tool head **30** positions each of these devices at a relative rotational and vertical position within the interior of the cabinet **11** in order to perform their respective functions, as further described herein. It should be appreciated that each of the particular devices or tools provided on the tool head **30** in the illustrated embodiment is not essential, nor limiting. For example, in alternative embodiments, more or less devices/tools may be carried on the tool head **30**. For example, only a single capping device (e.g., **42** or **44**) may be employed and/or the reader **31** may be provided in a location separate from the tool head **30**, including not being within the cabinet **11**. By way of further example, the slide loading platform **46** may be omitted in some embodiments, wherein the system operator loads the slides directly into a slide holder such as or similar to slide holder **57**. These and other variations and permutations of the provisional of devices/tools on the tool head **30** are also contemplated within the scope of the present disclosure.

(27) As seen in FIGS. **3** and **4**, a pump **47** having a pump head **49** supplies pressurized air that is stored in a high-pressure tank **71** that supplies pressurized air for operating various pneumatic devices location in the cabinet **11** via manifold of solenoid valves **68** and connectors **67**. A slightly elevated pressure tank **72** and a slightly negative pressure tank **73**, respectively, are also provided for operation of the specimen transfer device **40** (described below in greater detail). For clarity, communication pathways of the pressurized air, such as solid and/or flexible tubing lines interconnecting the pump **47** to the tank **71**, and the tank **71** to the various pneumatic devices are not shown in order to more clearly view the system components located in the cabinet **11** without being obscured by the tubing. However, a flexible conduit **23** through which various pneumatic tubing and electrical conducts are connected to the tool head **30** and the various devices thereon, such as (without limitation) the cappers **42**, **44**, pipettor **37** and the specimen transfer device is shown in FIG. **2** (only). Bundling the various tubing and wires through the single conduit **23** reduces the chance of snagging or displacing a tube or wire from a connector by operation of the tool arm **30**. Notably, the lengths of the tubing and electrical connections that pass through the conduit **23** are sufficiently long to allow the conduit **23** can to move with the tool head **30** as the tool head **30** translates linearly along its vertical axis **51** and rotates about its rotational axis **33**.

(28) Referring back to FIGS. **2** and **3**, the reader **31** is configured to read identifying indicia such as (without limitation) patient identification and/or medical record identifiers, a date on, or medical establishment at, which the sample was obtained, etc., on any of the sample container **12**, aliquot container **20**, slide **50** and/or filter **54**. The reader **31** may be an optical reader or scanner, such as for reading barcodes, QR codes, machine readable alphanumeric text and/or an optical camera that acquires an image of a label that may then be read and/or recognized using optical character recognition (OCR) software, or an electronic reader configured to read an NFC chip, RFID or other electronic tag, or other reader configured to read a readable indicia. Examples of such alternate indicia storage techniques for slides are provided in U.S. Pat. No. 7,083,106 and U.S. Pat. Publ. No. 20070148041, the disclosures of which are incorporated herein by reference in their entirety. In the illustrated embodiment, the reader **31** is configured among other capabilities to read indicia in form of a bar code. Indicia on the sample container **12** is read by the reader **31** and transmitted via the system controller **60** (described below in further detail) to each of the slide printer **13** and the aliquot container printer **19** for printing a matching or otherwise corresponding indicia on a respective slide **50** and/or aliquot container **20** to be used in a sample processing procedure.

(29) With reference (primarily) to FIGS. **2-5**, a pipette tip dispenser gantry or “transporter” **22** is coupled to the chassis **14** forward of the aliquot container holder **18**. The pipette tip dispenser transporter **22** includes a pipette tip dispenser holder **24** configured for securely seating a pipette tip dispenser **26** thereon. The pipette tip dispenser is configured for holding a plurality of pipette tips **48**, e.g., eight pipette tips in the illustrated embodiment, wherein the dispenser may be supplied as a pipette tip cartridge. The pipette tip dispenser **26** may be removably mounted to the holder **24** in

any of a number of ways. In the illustrated embodiment, the pipette tip dispenser **26** is magnetically coupled to the pipette tip dispenser holder **24** in a manner that ensures precise and predictable positioning of the dispenser **26** relative on the holder **24**, and which also allows for the system controller **60** (further described below) to confirm through a sensor circuit that the dispenser **26** is properly attached and positioned relative to the holder **24**. This is important to ensure that the pipette tip engaging member **38** carried by the tool head **30** can exactly align with, to thereby engage a pipette tip **48** held in a respective slot of the dispenser during a sample processing procedure.

(30) With brief reference also to FIG. **16**, lateral translation of the pipette tip dispenser transporter **22** is performed by a motorized drive belt **87** that spins back and forth on drive wheels **80***a* and **80***b* underlying a bottom surface of the chassis **14**. The drive wheels in turn rotate respective shafts (not shown) that extend back through the chassis floor and are mechanically coupled to the transporter **22** for translating same to laterally move the pipette tip holder **24** and the pipette tip dispenser **26** mounted thereon between a storage position, in which the pipette tip dispenser is located within an isolation chamber **28**, as shown in FIG. **4**, and a loading position as shown, in which a slot of the pipette tip holder **26** containing an available pipette tip **48** is aligned with the pipette tip engaging member **38** on the tool head **30**, as shown in FIG. **7**. In particular, the loading position will vary depending upon which slot(s) of the dispenser **26** are occupied by pipette tips. In the storage position, the respective pipette tip holder **24**, and the pipette tip dispenser **26** mounted thereon, are positioned within an isolation chamber **28** located within the sample processing cabinet **11** in order to reduce the chances of contamination of unused tips from the sample processing activities taking place in the main interior region of the cabinet **11**.

(31) As can be seen by comparing FIG. **4** and FIG. **5**, a panel **52** (FIG. **4**) is attached to a side of the pipette tip dispenser **26** and is sized and shaped to close an opening through which the holder **24** and dispenser **26** enter the isolation chamber **28**. As seen in FIG. **3**, a pipette tip sensor **35** located in the isolation chamber **28** tracks the pipette tips **48** held in the dispenser **26** to inform the system controller **60** on same for precisely moving the pipette tip dispenser transport **22** to a location in which a tip **48** held in the dispenser **26** is aligned with the pipette tip engaging member **38** on the tool head **30**, and also to ensure that there are adequate pipette tips available in the dispenser **26** to perform the particular sample processing procedure. If the dispenser **26** is empty or otherwise holds an insufficient amount of pipette tips **48** to perform a particular sample processing procedure, then system **10** will pause and not perform any further sample procedures until new pipette tips **48** have been loaded into the dispenser **26**.

(32) A used pipette tip waste bin **25** is mounted on a separate platform/holder **27** attached to the pipette tip transporter **22**, wherein the pipette tip dispenser transporter is configured to selectively translate the pipette tip waste bin **25** to a location at which the tool head **30** positions the pipette tip engaging member **38** to disengage an engaged pipette tip **48** into the waste bin **25**. As with the pipette tip dispenser **26** and holder **24**, the waste bin **25** is preferably magnetically coupled to holder **27** for both providing stability and to allow the system **10** to confirm via a sensing circuit that the waste bin is properly attached. In particular, the pipette tip waste bin holder **27** is mounted on the pipette tip transporter **22** relative to the pipette tip dispenser holder **24** such that, when the pipette tip dispenser **26** is translated into the isolation chamber **28**, the pipette tip waste bin **25** is simultaneously translated to the location at which the tool head **30** positions the pipette tip engaging member **38** to disengage an engaged/used pipette tip **48** into the waste bin **25**.

(33) With reference also to FIG. **15**, the pipettor **37** is disposed on the tool head such that the pipette tip engagement member **38** is at a slight angle relative to the pipette tip dispenser **26**. Similarly, are slightly angled so that the engaging member can mate to thereby engage a pipette tip **48** held in one of the slots by one or both of rotational and translational motion of the tool head **30**. The pipettor **37** may be, for example and without limitation, a Cavro® Air Displacement Pipettor (ADP) sold by Tecan Group Ltd. (www.tecan.com/components), having including a spring biased

engaging tip **53** (shown in FIG. **15**) that releasably engages the respective pipette tips by a compression fit of the engaging tip **53** as it is inserted into the bore of a respective pipette tip **48**. Once a pipette tip **48** is engaged (or installed) on the pipette tip engaging member **38**, the pipettor **37** is configured to selectively draw liquid from a sample container **12** into the pipette tip **48**, and to dispense the drawn liquid contained in the pipette tip **48** into an aliquot container **20**, respectively.

(34) In this manner, during a sample processing procedure, the pipettor **37** engages a pipette tip **48** from the pipette tip dispenser **26**. The pipettor is then repositioned by the tool head **30** to position the engaged tip into an open container (e.g., an open sample container **12**). In a known fashion, the pipette tips **48** are made of a conductive material (such as a conductive polymer) in order to use an impedance sensing circuit of the pipettor **37** to confirm that the pipette tip **48** is submerged in the liquid for drawing a sample, e.g., an aliquot from the sample container, by supplying a vacuum within the bore of the pipette tip **48** to thereby draw a volume of the sample into the pipette tip **48**. The pipettor **37** dispenses the sample drawn into the pipette tip **48**, e.g., into an open aliquot container **20**, by releasing the vacuum allowing the sample to dispense out of the pipette tip **48**. The pipettor **37** is configured and operates such that only the pipette tip **48** comes into contact with the sample material so that the pipette tip engaging member **38** of the pipettor **37** is not contaminated by the sample material. The pipette tip engaging member **38** is configured to disengage the pipette tip **48** into the waste container **25** after use by movable displacement sleeve that pushes the tip **48** off the tip **53** of the pipette tip engaging member **38**.

(35) The specimen transfer device **40** is carried by the tool head **30** and is configured to collect a specimen sample from the sample in the sample container **12** and to transfer the collected specimen sample to a slide **50**. In the described embodiment, the specimen transfer device **40** includes a cylindrical working end portion that extends away from the tool head **30** and is configured to form a pressure-tight seal around its circumference with a filter **54** that is seated thereon prior to initiating a sample processing procedure, as shown in FIG. **4**. The filter **54** includes a hollow cylindrical body having an open proximal end and a membrane spanning across its distal end having pores of a selected size to capture desired cells for the specimen sample and to pass smaller cells and non-cellular particles and liquids therethrough. Embodiments of the filter **54**, as well as of specimen sample collection and transfer devices and techniques suitable for use with the illustrated system **10** are disclosed and further described in U.S. Pat. No. 8,119,399, U.S. Pat. Publ. No. 20050100483 and U.S. Pat. Publ. 20080145887, the disclosures of which are incorporated herein by reference in their entirety. When installed on the working end of the specimen transfer device **40**, the filter **54** extends away from the tool head **30** by a sufficient distance to allow the filter to be inserted into the sample container **12** to collect a specimen sample on the membrane of the filter **54** without the sample liquid coming into contact with any part of the specimen transfer device **40**, such that only the filter contacts the sample liquid. This ensures that the specimen transfer device **40** is not contaminated by the sample material when it collects a specimen sample from the sample container **12**. Once the specimen transfer device **40** has collected a specimen onto the sample collector **54**, it is then manipulated to transfer the specimen from the filter **54** to the slide **50**, as described in more detail below.

(36) In particular, the specimen transfer device **40** and the system **10** are configured to insert the membrane of the filter into the sample in the sample container via one or both of translational and rotational motion of the tool head **30**, and to force the sample back and forth through the membrane to collect the specimen sample onto the membrane in a “sipping” manner, which deposits a thin layer of cells in the liquid sample onto the outside surface of the membrane. The specimen transfer device **40** may be configured to cycle a vacuum (and pressure) within the working end of the specimen transfer device in order to force the sample back and forth through the membrane. In addition, or alternatively, the specimen transfer device **40** and system **10** may be configured to move the membrane up and down within the sample in order to force the sample back and forth through the membrane in order to collect the specimen sample on the membrane. Methods and

apparatus for determining whether a sufficient amount, but not too many, cells have been collected by on the filter membrane using this same "sipping process" are disclosed and described in the above-incorporated U.S. Pat. No. 8,119,399. Further details of the specimen collection process in general, and of design and operation of the specimen transfer device **40** (and filter **54**) is found in to U.S. Pat. No. 8,137,642, the disclosure of which is incorporated herein by reference in its entirety, as well as several other of the above-incorporated patents. With brief reference to FIG. **17**, waste liquid from the specimen collection process is removed out of ports **95** located in the back of the cabinet **11**.

(37) The sample container capping device **42** comprises movable pneumatic prongs or "grippers" configured to grip and hold a cap **43** of a sample container **12**. As can be seen in FIG. **15**, the grippers are actuated by a pneumatic force supplied on an actuation member **77** to alternatively provide a tweezer-like radially inward gripping motion, or a radially outward release motion. The two or more grippers are preferably disposed substantially evenly about the circumference of the sample container cap **43** and can be placed into a "capping" or "uncapping" position by one or more of translational and rotational motion of the tool head **30**. In the case of removing the cap **43**, the capper **42** grips the cap **43** while the container holder **16** is rotating in one of a clockwise direction or counterclockwise direction, and the tool head **30** rises slightly and steadily upward to allow the cap **43** to travel upward as it rotates on the threads (not shown) of the container **12**. In the case of installing a cap **43** that is held by the grippers back onto the container **12**, the tool head **30** positions the capper **42** over the open container and travels slightly and steadily downward as the holder **16** rotates in the other of the clockwise direction and counter-clockwise direction while the tool head **30** lowers slightly and steadily to allow the cap **43** to travel downward onto the container **12**, as the container is rotated by the holder **16** relative to the cap **43**. The grippers used for the sample container capping device **42**, and also for the below described aliquot container capping device **44** include Parallel Style Air Gripper/2 Finger, 3 Finger and 4 Finger series grippers available from SMC Pneumatics.com.

(38) The aliquot container capping device **44** operates substantially the same way as the sample container capper, including using two or more prongs or grippers to releasably grip the cap **45** of an aliquot container **20** while the aliquot container holder is rotated in a clockwise or counterclockwise direction to respectively remove or install the cap **45** from or onto the container **20**. Again, the tool head **30** moves steadily downward or upward to accommodate the motion of the cap relative to the container **20** during the process. Notably, because less torqueing force is needed for uncapping and capping the aliquot container **20**, as seen in FIG. **15**, direct air pressure supplied through hose attachments **75** is used to power the aliquot container grippers.

(39) The sample container capping device **42** and the aliquot container capping device **44** are preferably positioned and oriented on the tool head **30** so that both capping devices **42** and **44** are in proper position to remove the respective caps **43** and **45** without requiring repositioning of the tool head **30**.

(40) It should be appreciated that, in alternate embodiments, the respective cappers **42** and **44** may be rotatable, in which case the capping process would include having capper **42** grip cap **43** and rotate while the sample holder remains stationary, and capper **44** grip caps **45** and rotate while the aliquot holder **18** remains stationary, such as taught in the above-incorporated U.S. Pat. No. 9,335,336 and U.S. Pat. Publ. no. 2017/0052205.

(41) The slide loading platform **46** is preferably positioned on the tool head **30** at a location convenient for a system operator to load a slide **50** thereon prior to a sample processing procedure, and is configured to receive and hold the slide **50** when it is loaded thereon. Although the loading platform **46** in this described embodiment is configured to receive and hold a microscope slide as the slide **50**, it is to be understood that the loading platform **46** may be configured to receive and hold other types of analytic elements other than slides, depending on the type of sample specimen to be output by the system **10**.

(42) As mentioned above, the slide positioner **56** includes a slide holder **57** having pneumatic grippers **59** configured to grip and remove a slide **50** from the loading platform **46** (the transfer is seen in FIG. **5**), and to thereafter position the slide for receiving the specimen sample obtained by the specimen transfer device **40**. The slide positioner is also movable in at least two degrees of freedom supplied by a slide positioner motor **63**, and various hinged arms, and is supported by a counterweight **64**. After the membrane of the filter **54** is pressed against the slide **50** to transfer the specimen sample (FIG. **12**), the slide positioner moves and rotates the slide **50** 90 degrees proximate an open container of fixative **58** seated in a fixative container holder **61** includes a slide positioner **56** which is configured to grip and move the slide **50**. Towards this end, the slide positioner **56** includes a pneumatically controlled gripper **59** configured to grip and thereby remove the slide **50** from the loading platform **46**, as shown in FIG. **5**. The slide positioner **56** then moves the slide to a transfer position in which the specimen transfer device **40** can transfer a specimen sample from the filter **54** to the slide **50** as shown in FIG. **11**, and then to a fixative position in which the analytic positioner **50** can place the slide **50** into a fixative container **58** containing a fixative for affixing the specimen sample to the slide **50**. The system **10** includes a fixative container holder **61**.
(43) With reference to FIG. **17**, the system **10** also includes one or more processors that may be collectively referred to as a controller **60** located in a back panel of the cabinet. The controller **60** is operatively coupled to, and configured to communicate with, and to control the automatic operation of, the various components of the system **10**, including the tool head **30**, tool head actuator **32**, pipettor **37**, specimen transfer device **40**, first capping device **42**, second capping device **44**, slide positioner **56**, and reader **31**. The controller **60** includes a computer processor, input/output interfaces and other supporting electronics for communicating with and controlling the operation of the components of the system. The controller **60** has a user input device for allowing a system operator to input commands, data, etc. into the controller **60**. The user input device may be a touchscreen/display **62**, as described below. The controller **60** also has system software for programming the controller **60** to communicate with and control the system **10** to perform the process of preparing a sample specimen and/or an aliquot sample from a biological or other sample contained in a sample container **12**, as described herein. In the illustrated embodiment. The touchscreen/display **62** is attached to the chassis and preferably integrated into the cabinet housing so as to be disposed to allow a system operator to input instructions (for example, if prompted by the system **10**), and review status of the items performed during a sample processing procedure. The touchscreen/display **62** is configured for displaying graphics generated by the controller **60**, including information regarding the operation of the system **10**, such as status of the operation, data, etc. The touchscreen/display **62** may be any suitable display such as a liquid crystal display (LCD), LED display, AMOLED, etc.
(44) An exemplary sample processing procedure will now be described with reference to FIGS. **1-14** in order to further illustrate and describe the various elements and components of the system **10**. In particular, the exemplary sample processing includes initially obtaining an aliquot of the sample, and thereafter processing the sample to create a biological specimen slide. This process is described for purposes of illustration, and not limitation, and it should be understood that other types of sample processing may be performed using the disclosed and described system and variations thereof, while remaining within the scope of the present disclosure. By way of example and without limitation, each of the method of using an automated system to process a sample contained in a sample container set forth in the appended claims hereto should be considered as additional exemplary sample processing procedures that may be performed using the illustrated system **10**.
(45) To initiate processing of a given patient sample container **12**, a system operator enters an instruction for same, e.g., by contacting a “start button” or similar symbol on the user interface **62**. The system controller **60** causes the tool head **30** to assume an “initiation” position (if the tool head **30** is not otherwise not already in this position), in which the tool head **30** is positioned and rotated

within the cabinet **11** to position the reader **31** in a convenient location for the system operator to present the sample vial **12**, such as seen in FIG. **4**.

(46) After receiving a visual confirmation from the system controller **60** on the user interface display **62**, the system operator presents the sample container **12** to the reader **31**, so a patient and/or other indicia on the sample container **12** is within the field of view of the reader **31**. The reader **31** reads the indicia on the sample container **12** and communicates same (via the controller **60**) to the respective slide printer **13** and aliquot container printer **19**. The slide printer automatically prints and outputs a new (i.e., unused) slide **50**, wherein indicia matching or otherwise corresponding to the indicia on the sample container **12** is printed on the slide **50**. The system operator also inserts a new (i.e., unused) aliquot container **20** into the aliquot container printer, which prints indicia on the aliquot container **20** that also matches or otherwise corresponds to the indicia on the sample container **12**.

(47) The pipette tip dispenser transporter **22** is moved to the loading position (FIG. **2**) to expose the pipette tip dispenser **26** in case additional tips **48** must be added. Loading the system **10** with the sample container **12**, the aliquot container **20**, the slide **50** and the pipette tip dispenser **26** may be automated using automation such as robots, or it may be performed manually by a system operator —the later being assumed in this example for simplification. In particular, the system operator then loads the (capped) sample container **12** into the sample container holder **16** and loads the (capped) aliquot container **20** into the aliquot container holder **18**, in each case after having the reader **31** read and confirm that the respective sample and aliquot container indicia match. The system operator loads the slide **50** onto the slide loading platform **46** in a face down orientation, i.e., with the side of the slide having the printed indicia and the “cell spot” area to receive the specimen sample facing downward into the platform **46**, The system operator and loads a new filter **54** onto the working end of the specimen transfer device **40**, and confirms that there are an adequate (at least one) number of unused pipette tips **48** in the pipette tip dispenser **26** and that the pipette tip waste bin **25** is empty. Once all of the consumables are loaded, the system operator closes the door **15** of the cabinet **11** and indicates via the user interface that the sample processing procedure may be commenced, assuming all of the system verifications are complete.

(48) Notably, the system **10** will not initiate the sample processing procedure unless the sensor **35** indicates that a sufficient number of pipette tips **48** are in the dispenser **26**, even if this means just one, and also that the pipette tip dispenser **26** and waste bin **25** are properly seated and magnetically coupled to their respective mounting platforms **24** and **27** on the pipette tip dispenser transporter **22**. The specimen transfer device **40** performs a “dry” test to verify the integrity of the filter **54**, in particular, to confirm distal end membrane has not been punctured (indicating the filter **54** has been previously used) or otherwise occluded or torn. Notably, once it is confirmed that there are adequate pipette tips **48**, the pipette tip dispenser transporter is moved by the system so that the pipette tip dispenser is located in the isolation chamber **28** From that point until the sample processing procedure is completed, no further system operator involvement is normally required.

(49) As shown in FIGS. **4-6**, at the beginning of the sample processing procedure, the pipette tip dispenser transporter **22** moves the pipette tip dispenser into the storage position in the isolation chamber **28** (FIG. **3**), and the tool head **30** rotates slightly upwards and also linearly translates upward so that the slide **50** may be griped by the grippers **59** of the slide holder **57**. The tool head **30** then linearly translates downward and rotates so that the indicia on the side **50** may be read by the reader **31** to confirm the indicia matches that of the respective sample container **12** and aliquot container **20**. Assuming the match is verified, the system **10** continues with the then performs an automated process to prepare a specimen sample and an aliquot sample with each of the components of the system **10** operated and controlled by the controller **60**.

(50) As shown in FIG. **6**, the tool head **30** is rotated and moved vertically downward by the tool head actuator **34** to position the sample container capping device **42** over the cap **43** on the sample container **42** and the aliquot container capping device **44** over the second cap **45** on the aliquot

container **20**. The respective capping devices **42** and **44** remove and grip the caps **43** and **45** in cooperation with rotation of the respective container holders **156** and **18**.

(51) As shown in FIG. **7**, the pipette tip dispenser transporter **22** moves to the loading position to position a pipette tip **48** contained in the pipette tip dispenser **26** to be installed on the pipette tip engaging member **38** of the pipettor **37**. Also shown in FIG. **7**, the tool head **30** rotates to position the pipette tip engaging member **38** to install the pipette tip **48** by respective rotation and translation of the tool head **30** to push the pipette tip engaging member into the pipette tip **48**.

(52) As shown in FIG. **8**, the pipette tip dispenser transporter **22** moves back to the storage position. The tool head **30** rotates and translates vertically to place the pipette tip **48** on the pipettor **37** into the sample in the sample container **12**. The pipettor **37** draws a vacuum within the pipette tip **48** to draw a volume of the sample (the aliquot sample) into the pipette tip **48**.

(53) As shown in FIG. **9**, the tool head **30** rotates and translates vertically to position the pipette tip **48** in the aliquot container **20**. The pipettor **37** releases the vacuum to dispense the aliquot sample out of the pipette tip **48** and into the aliquot container **20**. After the aliquot sample has been dispensed into the aliquot container **20**, the tool head **30** is rotated and translated to position the aliquot container capping device **44** in position to reinstall the cap **45** back onto the aliquot container **20** (same position as shown in FIG. **6**).

(54) As shown in FIG. **10**, the tool head **30** is rotated and translated to position the pipette tip **48** over or within the waste container **25**. The pipette tip engaging member **38** then disengages (ejects) the used pipette tip **48** into the waste container **25**.

(55) As shown in FIG. **11**, the tool head **30** is rotated and translated to position the filter **54** installed on the specimen transfer device **40** in position to collect a specimen sample from the sample container **20** onto the filter membrane according to the process described above, i.e., forcing the sample back and forth through the membrane either by a cycling vacuum and/or by moving the filter up and down, such as by moving the tool head **30** via the tool head actuator **34**. This process allows a thin layer or single layer of cells, to be collected on the membrane.

(56) As shown in FIG. **12**, the tool head **30** is rotated and translated to position the filter membrane in position to transfer the specimen sample to the slide **50** held by the grippers **59** of the slide holding device **57**. The specimen transfer device **40** and/or the slide positioner **56** are then manipulated to contact the membrane having the specimen sample thereon onto the slide **50**. The tool head **30** may be moved via the tool head actuator **34** to manipulate the specimen transfer device **40**. In order to provide for transfer of the specimen sample (e.g., a thin layer of cells) to the slide **50** without disturbing the spatial distribution thereof, it is desirable that the membrane of the filter **54** first contact the slide **50** generally at a single location, forming a predetermined small pre-contact angle between the membrane and a deposition surface of the slide **50**, and then gently and gradually enter into complete contact with the slide **50**. This may be accomplished by manipulating the specimen transfer device **40** and the slide positioner **56** in coordination.

(57) As shown in FIG. **13**, the tool head **30** is moved downward and may also be rotated to provide room for the slide positioner **56** to place the slide **50** having the specimen sample thereon into a fixative container **58** containing fixative for affixing the specimen sample onto the slide **50**. After transferring the specimen sample to the slide **50**, the tool head **30** translates and/or rotates to drive the filter membrane into a pin **41** (FIG. **4**) in order to destroy the filter membrane to prevent reuse. As also shown in FIG. **13**, the slide positioner **56** is actuated to place the slide **50** having the specimen sample thereon into the fixative container **58**. Once the sample processing procedure is completed, a system operator may remove the specimen slide **50** from the fixative solution in container **58**, or alternatively may remove the fixative container, including the specimen slide **50**, and replace the fixative container **58** (or place a new one) in the holder **61** prior to commencing a new sample processing procedure.

(58) The tool head **30** is rotated and moved downward to position the sample container capping device **42** in position to reinstall the cap **43** back onto the sample container **12** (same position as

shown in FIG. **4**).
(59) This completes the automated process for preparing the specimen sample and aliquot sample. The slide **56** having the specimen sample affixed thereon by the fixative can then be removed from the fixative container **58** and utilized for testing. The sample container **12** and the aliquot container **20** may also be removed from the system **10** and stored appropriately. The waste container **25** is removed from the system **10** and dumped into a waste bin to dispose of the used pipette tip **48**. The waste container **25** may then be placed back onto the waste container platform **27**.
(60) The process as described may be repeated for additional sample containers having respective sample contained therein, as desired.
(61) Although particular embodiments have been shown and described, it is to be understood that the above description is not intended to limit the scope of these embodiments. While variations of the many aspects of the herein disclosed embodiments have been illustrated disclosed and described, it should be appreciated that the foregoing disclosure is provided for purposes of explanation and illustration only, and that various changes and modifications may be made to the disclosed embodiments without departing from the scope of the following claims. For example, not all of the components depicted and described in the embodiments are necessary, and the alternative embodiments may include any suitable combinations of the described components, and the general shapes and relative sizes of the components may be modified.

Claims

1. An automated system for processing a sample contained in a liquid sample container, the automated system comprising: a sample container holder configured to hold a sample container; an analytic element holder configured to hold an analytic element; a tool head configured to rotate about a first axis; a lead screw connected to the tool head; a tool head linear actuating motor configured to rotate the lead screw to translate the tool head along a second axis different than the first axis; a specimen transfer device carried by the tool head at a first position on the tool head, wherein, through one or both of rotation of the tool head about the first axis and translation of the tool head along the second axis, the tool head is configured to position a working end of the specimen transfer device to obtain a specimen from a sample container held in the sample container holder and to transfer the obtained specimen to an analytic element held by the analytic element holder; and a system controller operably coupled to the tool head, the specimen transfer device, and the tool head linear actuation motor, the system controller configured to provide automated operation of the tool head, the specimen transfer device and the tool head linear actuating motor.
2. The automated system of claim 1, further comprising a filter having a tubular body and a porous membrane end portion, wherein the tubular body of the filter forms a seal with the working end of the specimen transfer device, and wherein the porous membrane end portion is configured to allow liquid to pass therethrough while retaining cellular matter on an outer surface of the porous membrane end portion.
3. The automated system of claim 2, further comprising the analytic element, wherein the analytic element comprises a slide.
4. The automated system of claim 1, further comprising a user interface operatively coupled with the controller and configured for displaying system status and/or inquiries to a user and for receiving user inputs in response to the displayed system status and/or inquiries.
5. An automated system for processing a sample contained in a liquid sample container, the system comprising: a sample container holder configured to hold a sample container; an analytic element holder configured to hold an analytic element; a tool head configured to rotate about a first axis and to translate along a second axis different than the first axis; a specimen transfer device carried by the tool head at a first portion on the tool head, wherein, through one or both of rotation of the tool head about the first axis and translation of the tool head along the second axis, the tool head is

configured to position a working end of the specimen transfer device to obtain a specimen from a sample container held in the sample container holder and to transfer the obtained specimen to an analytic element held by the analytic element holder; a sample container capping device disposed on the tool head at a second position on the tool head different from the first position, the sample container capping device configured to controllably grip and release a cap of a sample container held in the sample container holder, wherein the tool head is configured to automatically position the sample container capping device relative to the sample container cap through one or both of rotation of the tool head about the first axis and translation of the tool head along the second axis, and wherein the sample container capping device operatively cooperates with the sample container holder to remove or install the sample container cap; and a system controller operably coupled to the tool head, the specimen transfer device, and the tool head linear actuating motor, the system controller configured to provide automated operation of the tool head, the specimen transfer device and the tool head linear actuating motor.

6. The automated system of claim 5, wherein the sample container holder is configured to rotate in one of a clockwise rotational direction and a counter-clockwise rotational direction while the sample container capping device engages the sample container cap in order to remove the sample container cap from the sample container, and wherein the sample container holder is configured to rotate in the other one of the clockwise rotational direction and the counter-clockwise rotational direction while the sample container capping device engages the sample container cap in order to install the sample container cap onto the sample container.

7. An automated system for processing a sample contained in a liquid sample container, the system comprising: a sample container holder configured to hold a sample container; an analytic element holder configured to hold an analytic element; a tool head configured to rotate about a first axis; a specimen transfer device carried by the tool head at a first portion on the tool head, wherein, through one or both of rotation of the tool head about the first axis and translation of the tool head along the second axis, the tool head is configured to position a working end of the specimen transfer device to obtain a specimen from a sample container held in the sample container holder and to transfer the obtained specimen to an analytic element held by the analytic element holder; a pipette tip dispenser, a pipettor carried by the tool head at a third position on the tool head different from the first position, the pipettor having a pipette tip engaging member configured to releasably engage pipette tips, wherein the tool head is configured to position the pipette tip engaging member relative to the pipette tip dispenser to allow the pipette tip engaging member to engage a pipette tip held by the pipette tip dispenser through one or both of rotation of the tool head about the first axis and translation of the tool head along the second axis; and a system controller operably coupled to the tool head, the specimen transfer device, and the tool head linear actuating motor, the system controller configured to provide automated operation of the tool head, the specimen transfer device and the tool head linear actuating motor.

8. The alternated system of claim 7, further comprising a pipette tip dispenser transporter, wherein the pipette tip dispenser is mounted on the pipette tip dispenser transporter, wherein the pipette tip dispenser transporter is configured to translate the pipette tip dispenser relative to the tool head so that the pipette tip dispenser may be selectively translated to a location at which the tool head positions the pipette tip engaging member to engage a pipette tip from the pipette tip dispenser, and wherein the system controller is operably coupled to the pipette tip dispenser transporter and configured to provide automated operation of the pipetter tip dispenser transporter.

9. The automated system of claim 8, further comprising a pipette tip dispenser isolation chamber, wherein the pipette tip dispenser transporter is configured to selectively translate the pipette tip dispenser between the location at which the tool head positions the pipette tip engaging member to engage a pipette tip from the pipette tip dispenser and a second location within the isolation chamber.

10. The automated system of claim 8, further comprising a pipette tip waste bin mounted on the

pipette tip transporter, wherein the pipette tip dispenser transporter is configured to selectively translate the pipette tip waste bin to a location at which the tool head positions the pipette tip engaging member to disengage a pipette tip into the pipette tip waste bin.

11. The automated system of claim 10, wherein the pipette tip waste bin is mounted on the pipette tip transporter relative to the pipette tip dispenser such that, when the pipette tip waste bin is translated to the location at which the tool head positions the pipette tip engaging member to disengage a pipette tip into the pipette tip waste bin, the pipette tip dispenser is simultaneously translated into the isolation chamber.

12. The automated system of claim 7, further comprising a supplemental container holder configured for holding a supplemental container, wherein, through one or both of rotation of the tool head about the first axis and translation of the tool head along the second axis, the tool head is configured to position the pipette tip engaging member at (i) a first position in which a pipette tip engaged on the pipette tip engaging member is inserted into a sample container held in the sample container holder and (ii) a second position in which the engaged pipette tip is inserted into a supplemental container held in the supplemental container holder.

13. The automated system of claim 12, further comprising a supplemental container capping device disposed on the tool head and configured to controllably grip and release a cap of a supplemental container held in the supplemental container holder, wherein the tool head is configured to position the supplemental container capping device relative to the supplemental container cap through one or both of rotation of the tool head about the first axis and translation of the tool head along the second axis, and wherein the supplemental container capping device operatively cooperates with the supplemental container holder to remove or install the supplemental container cap.

14. The automated system of claim 13, wherein the supplemental container holder is configured to a rotate in one of a clockwise rotational direction and a counter-clockwise rotational direction while the supplemental container capping device engages the supplemental container cap in order to remove the supplemental container cap from the supplemental container, and wherein the supplemental container holder is configured to rotate in the other one of the clockwise rotational direction and the counter-clockwise rotational direction while the supplemental container capping device engages the supplemental container cap in order to install the supplemental container cap onto the supplemental container.

15. The automated system of claim 13, further comprising an aliquot container held in the supplemental container holder, wherein the tool head and pipettor operatively cooperate to cause the pipette tip engaging member to engage a pipette tip from the pipette tip dispenser, draw an aliquot of a sample from a sample container held in the sample container holder using the engaged pipette tip, and dispense the obtained sample aliquot into the aliquot container.

16. The automated system of claim 13, further comprising a reagent container held in the supplemental container holder, the reagent container containing a reagent, wherein the tool head and pipettor operatively cooperate to cause the pipette tip engaging member to engage a pipette tip from the pipette tip dispenser, draw an aliquot of reagent from the reagent container using the engaged pipette tip, and dispense the reagent aliquot into a sample container held in the sample container holder.

17. The automated system of claim 14, further comprising an analytic element positioner configured to engage an analytic element, wherein the analytic element positioner operatively cooperates with the tool head to position an engaged analytic element proximate the working end of the specimen transfer device to transfer the specimen onto the engaged analytic element.

18. The automated system of claim 17, further comprising a fixative container holder, wherein the analytic element positioner is configured to place an analytic element carried by the analytic element positioner into a fixative container held in the fixative container holder after a specimen has been transferred onto the analytic element.

19. The automated system of claim 17, further comprising an analytic element loading platform

located on a surface of the tool head, wherein the analytic element positioner operatively cooperates with the tool head so that the analytic element holder engages and removes an analytic element placed on the loading platform, and wherein the analytic element positioner operatively cooperates with the tool head to position an engaged analytic element relative to the working end of the specimen transfer device to transfer the specimen onto the engaged analytic element engaged by the analytic element holder.

20. An automated system for processing a sample contained in a liquid sample container, the system comprising: a sample container holder configured to hold a sample container; an analytic element holder configured to hold an analytic element; a tool head configured to rotate about a first axis and to translate along a second axis different than the first axis; a reader positioned on the tool head and configured for reading sample container indicia located on a sample container; and an analytic element printer in communication with reader and configured for printing analytic element indicia corresponding to sample container indicia read by the reader onto an analytic element; a specimen transfer device carried by the tool head at a first portion on the tool head, wherein, through one or both of rotation of the tool head about the first axis and translation of the tool head along the second axis, the tool head is configured to position a working end of the specimen transfer device to obtain a specimen from a sample container held in the sample container holder and to transfer the obtained specimen to an analytic element held by the analytic element holder; a system controller operably coupled to the tool head, the specimen transfer device, and the tool head linear actuating motor, the system controller configured to provide automated operation of the tool head, the specimen transfer device and the tool head linear actuating motor.