CoviDetect

Automatic COVID-19 Testing Solution

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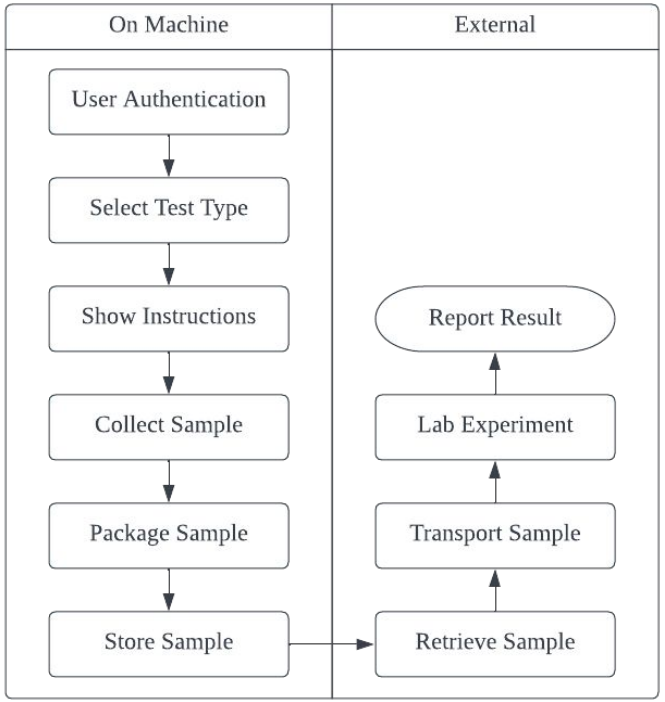
Introduction

- Huge demand for COVID-19 testing services
- Conducting a convenient test on site requires a complicated and expensive system
- Construct an unmanned COVID-19 testing solution
- Low fixed and variable cost, on-site convenience and reliability
- Main customers are organizations such as governments, schools, companies
- Machine is capable of: PCR Swab, PCR Saliva and Antigen Swab
- Antigen analyzed directly inside, PCR must be sent to labs for experiments

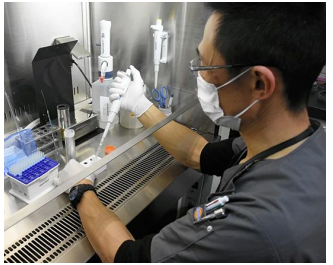
Operating Scenario

- Student Taps Univesity ID Card
- Student Selects Test Type
- Robotic Arm Collects Sample
- Machine Processes, Packs & Stores
- Employees Retrieve Sample
- Technicians Perform Experiment
- System Reports Result to University



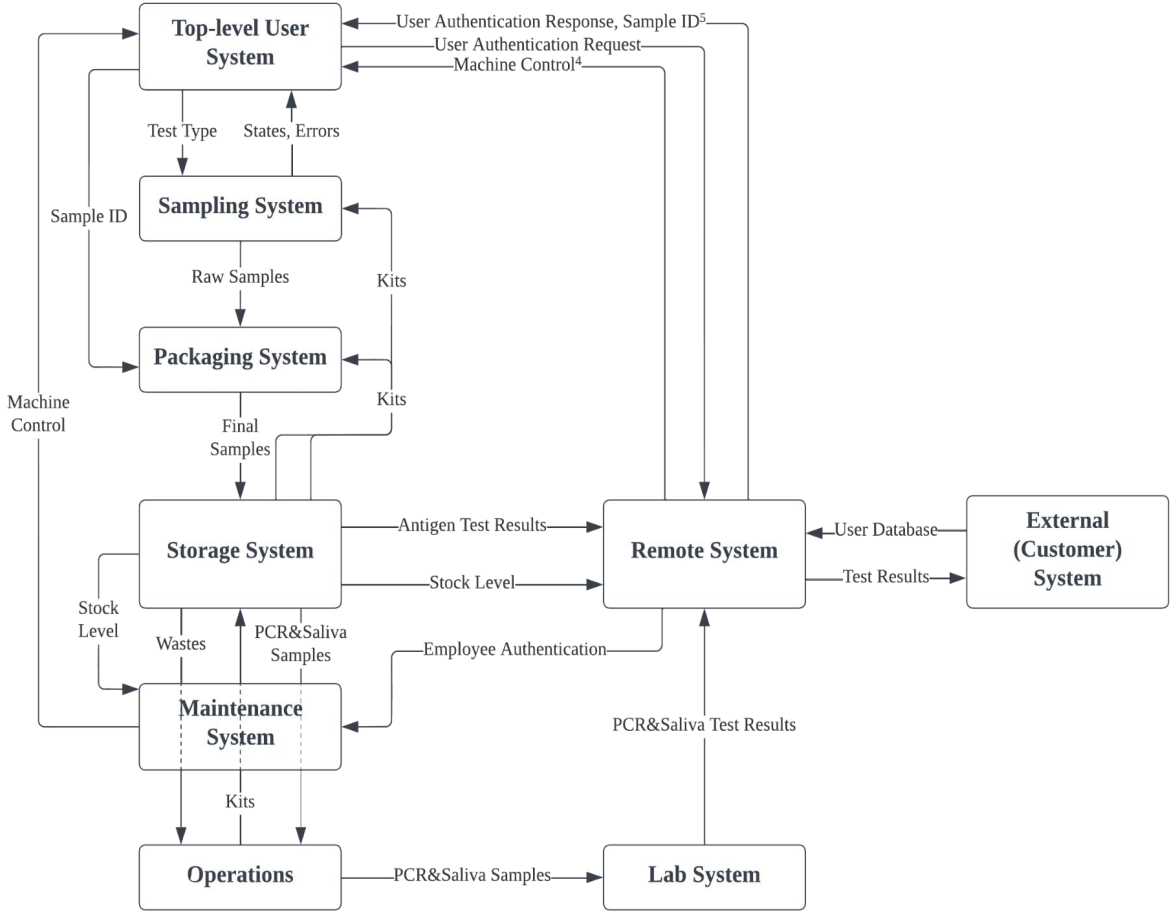
Stakeholders

- Customers (mainly organizations such as governments, schools, companies, etc.)
- Users (those people considered part of that organization, such as students inside a school, who will be getting a test)
- Health regulators (who permit the operation)
- Suppliers (who provide mechanical parts, testing kits, etc.)
- Manufacturers (who manufacture our testing machines)
- Employees (maintenance, delivery, lab, R&D, etc.)



Subsystems

- Top-Level User System
- Sampling System
- Packaging System
- Storage System
- Maintenance System
- Remote System
- Lab System
- Operation System
- External (Customer) System



Top-level User

- **The machine must be operable in most inhabited environments around the world.** We want to maximize the range of customers with different operating conditions.
- **The machine can be used by most people without external human guidance.** We want the design to be as accessible as possible. However, requiring human guidance introduces unnecessary labor costs and defeats our purpose of creating an automatic testing service.
- **The machine must be able to authenticate legal users.** We only want users that belong to the user group provided by the customer organization to be allowed to request a test, since unauthorized tests from outsiders will lead to unnecessary test costs paid by the customer organization.
- **The machine must allow the user to select a test type.**
- **The machine must convey test instructions to the user.** We expect the user to follow certain requirements before and during the testing process to ensure that the test is conducted effectively and safely.

Top-level User

Function	Implementation	Trade-Off
Display 	Use off-the-shelf LCD displays because they are relatively cheap.	LCD screens generally have lower brightness compared to OLED, which could cause visibility issues under sunlight if our machine is installed outdoors. However, OLED has a shorter lifespan and is too expensive for large screen sizes.
User Inputs 	Use touch inputs.	May not be intuitive to use for people who have limited experience interacting with smartphones. Less responsive if the screen is wet, which could happen if the machine is installed outdoors. Best alternative is to use a non-touching display plus some physical buttons, but will substantially restrict flexibility of feature updates in the future.

Top-level User

Risk	Possibility	Severness	Solution
Unusual Weather Conditions 	3; occasionally happens in all places	2; may cause minor or medium damage to hardware	Add water-proof, thermal insulation and other common capabilities
Unauthorized User Access 	2; possible due to design vulnerability	1; waste of test costs to customer organization, but still relatively inexpensive	Enforced user authentication; code quality inspections
Power Outage 	2; occasionally happens in places with less robust infrastructure	2; machine will become temporarily inoperable before recovery	Add UPS (Uninterrupted Power Supply) capability as power source backup

Top-level User

Component	Metric	Unit	Description
Exterior	Operating Temperature	˚C	Range of temperatures that the machine can operate normally. Must be sufficiently wide to endure extreme weather conditions.
Electricity	Power Input	V, Hz	Certain or a range of voltages and frequencies supplied by the outlet that the machine can accept. Must conform to local standards to avoid damaging the circuits.
Display	Maximum Brightness	nit	Maximum level of brightness that can be displayed. Impacts display visibility, especially under sunlight.

Sampling

- **The sampling system must be able to communicate with the storage system and packaging system.** We want to deliver test kits from the storage system to the sampling system and provide kits to users.
- **The sampling system must be able to perform tests safely and properly on users.** We want to perform three types of tests on users, in which two are nasal swabs and one is saliva collection.
- **The sampling system must be able to detect human faces and the position of the nose.** The system must use camera sensors to locate the user's nose position.
- **The sampling system must be able to communicate with the top-level user system.** Bidirectional Signaling.
- **The sampling system must be able to properly transfer a raw sample to a collection tube.** The sampling system should output collection tubes that contain saline solution to the packaging system.
- **The sampling system must be able to complete an antigen rapid test.** The sampling system should use the collection tube solution to perform an antigen test and report the result later, after raw sample transfer.

Sampling

Function	Implementation	Trade-Off
Robotic Arm	The robotic arm has these structures from bottom to top: a base, the first segment of the metallic arm, the “joint”, the second segment of the metallic arm, and the swab “holder”.	We need more motors for degrees of freedom and accuracy, but would introduce higher possibility of failure
Conveyor	Transport the test kit to user	The motor may stop working for many reasons. No better alternatives have been identified so far.
Face Detection	This component is implemented based on a micro camera sensor. Use CV program to calculate positions of user’s face and others.	Calculation error may cause the arm to aim wrongly and cause dangerous situations.

Sampling

Risk	Possibility	Severness	Solution
Robotic arm pushing too aggressively	1; the holder should move slowly	5; could threaten user's comfort and even safety.	Add damping to the holder's moving track and maintain a very small current.
Robotic Arm aims for the incorrect location	2; the detection software should have a higher than human average accuracy.	5; if mistakenly aims for other places like the eye, could threaten user's safety	Train the software to achieve better than human accuracy.
Robotic arm stuck/broken	2; the arm segment should be made with strong materials and the motor should have tens of thousands of lifetime, therefore low possibility	3; machine will stop providing any service until repair; requires replacement of expensive parts	Test the motors and the strength of the robotic arm once every two weeks to ensure they are working properly.

Sampling

Component	Metric	Unit	Description
Robotic Arm motors (including motors on the base, the joint, and the holder)	Rotation Speed	rad/s	How fast can the robotic arm move it's joint. The arm should move quickly with high degree of freedom.
Abort Button	Diameter	mm	How big is the abort button. The abort button should be big and visible to users.
Conveyor	Maximum Speed	cm/s	How fast can the conveyor move test kits to users.

Packaging & Storage

Packaging System Requirements:

- Must have enough space to store all samples
- Must have clear labels on samples collected from the sampling system
- Must have clear labels on packages that collect batches of sample tubes
- Must satisfy sanity and safety standards
- Temperature and humidity control

Storage System Requirements:

- Must have appropriate condition to keep the samples uncontaminated.
- Must arrange samples in the order of time arrived.
- Must meet sanity and safety standards
- Must store the wastes generated from the sampling system

Packaging & Storage

Function	Implementation	Trade-offs
Shock absorption	5 15'' x 20'' absorbent mat/box.	May be expensive but it prevents the spill of possible COVID-positive samples.
Leakproofing	5 1-gallon HDPE wide mouth jars per box. Put samples in batches into the jar.	May be environmentally unfriendly but can be cleaned and reused
Labeling	8.5'' x 11'' label paper/box	Another choice is printing the information on the box but it will create extra cost and work for printing
Temperature Conservation	2 scientific refrigerators	May also use ultra-low temperature freezers. There is not much difference between different freezers or refrigerators.

Packaging & Storage

Risk	Possibility	Severeness	Solution
Spill of Samples	2; done by the machine and collected in a capped tube.	5; we need to recollect the sample; the staff may be infected	Require staff to wear PPE
Sample Denature	3; may denature if the storage time is too long	3; we need to recollect the sample	Require low storage temperature
Missing samples (stuck and cannot be collected due to mechanical errors)	2; unlikely if design is well tested.	3; the customer may not receive the result	Count and record the number of samples.
COVID-Positive Waste	4; likely because the storage system will have direct contact with COVID-positive swabs.	5; the staff dealing with the waste may be infected.	Use BSL-3 level biohazard standard to build the waste storage system.

Packaging & Storage

Component	Metric	Unit	Description
Absorbent Packing Material	Absorbency	g/mm^2	Absorbency of packing material
Secondary Container	Water-proof Rating	IPX	Water conditions that the container can endure
Insulating material	Thermal Conductivity	$W/(m \cdot K)$	Thermal conductivity of insulating material; crucial for temperature preservation
Printer	Revolution	DPI	Revolution of the printer
Refrigerator	Temperature	˚C	Must be suitable to preserve samples
Biosafety Level	BSL-3	N/A	BSL-3 level to prevent spread of viruses

Remote

- **The remote system must be able to generate a sample id based on user information received.** This provides an easy way to uniquely identify a sample among all samples and establish the correspondence between sample and user.
- **The remote system must be able to retrieve employee ID given employee information received from another system.** This provides a convenient way to uniquely identify the employee in the system and verify whether an employee is valid or not.
- **The remote system must have an interface for the outside system to access a user's test result/stock level.** This provides an easy way for authorized personnels or external systems to access information needed without actually having to know how it functions.

Remote

Function	Implementation	Trade-Off
Generate sample id	Use a random seed e.g. current time or user info. Query database to confirm it's unique.	Process may take multiple rounds in order to succeed with large number of samples
Establish correspondence	Develop a one-to-one algorithm to convert employee/user info into ID; Store pairs e.g. (sample id, user id) into database and query	Algorithm may have flaws; Database needs frequent update with large number of samples
API access	Receive request and return the desired result by querying database/stored info	Outside systems may send multiple requests simultaneously, requiring strong ability to process data concurrently

Remote

Risk	Possibility	Severness	Solution
Algorithm Flaws	5; relatively easy to make programming mistakes	2; wrong information stored in the system or user unable to update or retrieve information	Add a rigorous testing process before an algorithm is deployed.
Database Failure	2; unlikely but possible; the database is usually hosted by reliable solutions	4; data loss and need time for recovery; whole system may shut down	Backup database to backup new information from time to time
Server Failure	2; unlikely but possible. Most errors might be discovered before deploying	4; whole system will shut down as services rely on servers; may cause some data loss	Data backup plan and use logs for the recovery process.

Remote

Component	Metric	Unit	Description
Server	**Average Response Time**	ms	Average amount of time for server to respond to a request for service
Database	**Throughput**	# queries /second	Measures how quickly the database server is able to process incoming queries
Algorithm Testing	**Failure rate**	%	Percent of failed test cases among all test cases

Maintenance

- **The system's software must be able to be updated quickly and conveniently.** We want to let developers conveniently apply new features to the software and minimize the downtime caused by updates.
- **The Maintenance System must notify the remote system if the storage capacity is over 80% of the designed capacity.** We want to make sure the garbage and sample storage system can be emptied and proceed with service before they get fully filled.
- **The Maintenance System must notify the remote system if any testing kit capacity is below 20% of the stock.** We want to make sure any testing kits can be restocked before none of the kits are available for vending.
- **The machine must have an easily accessible maintenance door for maintenance.**
- **The Maintenance System must get authentication from the remote system to verify the identity of maintaining employees.** We want to make sure only authorized people can maintain the system.

Maintenance

Function	Implementation	Trade-Off
Software update	Use over-the-air (OTA) update	If the update fails, more time is needed for mainters to go to the machine and fix the update issue physically. We can also let maintainer to go to each machine physically to update machine, but this method may require significantly more cost.
Stock communication	Use stock and capacity information from Storage system	A threshold is set for warning. The threshold set may not be the most suitable one, which will cause lower efficiency.
Maintenance authentication	The employee should authenticate and then be authorized for operations.	Authentication from remote systems takes time to process but is necessary for safety.

Maintenance

Risk	Possibility	Severness	Solution
Maintainer's mistake	5; completely unavoidable. Human errors are often unavoidable	2; Maintainers might perform wrong operations and damage the system, but any noticeable damage will be spotted	Mandate a detailed double-check procedure after maintenance is performed
Physical damage to the maintenance door	2; Unlikely but possible. Caused by human damage and weather	3; the related maintenance work cannot be performed	List maintenance door physical structure integrity as one of check list item for routine maintenance

Maintenance

Component	Metric	Unit	Description
Software	**Software update speed**	s	Time of software update needed per update. Must be short enough so that the impact of downtime can be negligible to customers
Storage	**Testing kit out of stock**	boolean	A boolean value to reflect to Operation & Remote system about testing kit out of stock
Maintenance	**Maintenance door size**	mm x mm	Size of the maintenance door

Recommendations

So far

- Generally feasible technically
- Worrisome safety measures
- Issue to get permisson from regulators
- Lack of funding to support modifications
- Potential medical accidents
- Lawsuits and investigations
- DO NOT move on to the next phase
- More feasibility and risk analysis