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Autonomous and Solar-Powered Surface Water Waste Cleaning Robot

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***Abstract:** Water pollution causedbyfloatinggarbagehasemergedasapressingenvironmentalchallengeaffectinglakesandponds through out the nation. Manual removal ofthisdebris remains labor-intensive,unpleasant,and largelyimpracticalfor widespread implementation.Thisrealitypromptedourteamtoinvestigatewhetherautomationcouldprovideamoresustainablesolutiontothis persistent problem.*

Our research and development journey involved extensive experimentation with various electrical motors, photovoltaic panels, programmable microcontrollers, and waterproof housing materials. The outcome was an autonomous floating vessel capable of independentnavigation whilecollectingsurfacewaste through anintegratedconveyorbelt mechanism.Theentiresystemoperates exclusively on solar energy, eliminating dependency on conventional power sources.

Comprehensive field testing evaluated performance using diverse waste materials including plastic bottles, food wrappers, fallen leaves,andstyrofoamcups.Thedevice successfullycapturedandcontainedmostdebristypeswithout significantdifficulty.Energy performanceexceededinitialexpectations,withsufficientsunlightenablingnearlycontinuousoperationthroughoutdaylighthours without battery depletion concerns.

However, development was not without challenges. Heavier debris occasionally caused mechanical jams within the conveyor system, requiring design modifications. Additionally, strong wind conditions sometimes pushed the vessel away from intended navigation paths, highlighting the need for improved stabilization features.

Despite these obstacles, this academic project evolved into something with genuine real-world applicability. We believe that with continuedrefinement,thissolar-poweredwastecollectionrobotcouldserveasaneffectivetoolforrestoringcleanlinessto polluted water bodies across the country, offering an environmentally friendly approach to aquatic ecosystem preservation.

***Keywords:** Autonomous Robot, Water Cleaning, Solar Powered, Waste Collection, Embedded Systems*

I. INTRODUCTION

Lastmonsoon,afewofuswalked pastBellandur Lakeherein Bangalore,andthesmellhitusbeforeweeven sawthewater.Foam covered large stretches of the surface, plastic bottles clustered near the shore, and food packets floated lazily with the breeze. It looked lesslikealakeandmorelikealandfillthatsomeonehadflooded.Thatsightstuckwith us,andwhen our professorasked us topickacapstoneproject,cleaningupwaterbodiesfeltlikeanobviouschoice.Now,peoplehavetriedtacklingthisproblembefore. Municipal workersrowout in boats, scoop up whatever theycanreach,androwback. Rinseandrepeat,dayafter day. Except they never really catch up—garbage accumulates faster than hands can grab it. Some cities brought in diesel-powered cleaning boats, whichworkfasterbutguzzlefuel,spewexhaust,andcostafortunetomaintain.Neitheroptionscaleswell,andneitherrunswithout constant human attention.

Robots seemed like a better bet. Machines don't get tired, don't complain about smelly water, and don't need lunch breaks. Slap somesolarpanelsontop,andsuddenlyyou'vegotsomethingthatfeedsitselfenergystraightfromthesky.Theideasounded almost too good, so we decided to actually build oneand see what happens. Our goals weremodest but clear. First, make something that floats without tippingover. Second, give itmotors strong enough topush through water but efficient enoughnot todrain batteries intenminutes.Third,attachsomekindofscooporconveyorthatgrabsfloatingjunk.Fourth,wireupsensorssotherobotcandodge obstacles on its own. Fifth, keep costs low enough that a small-town panchayat could realisticallyafford one someday. This work tracesourattempttomeetthosegoals,thelessonswelearnedfrom bothprogress andmissteps,andthepossibilitiesthatopenedup as the project evolved.

II. LITERATURE SURVEY

Rather than jumping straightintoprototyping, wespentthefirst stretch simplyreadingthrough pastwork in thisarea. Seeingwhat othershad alreadyexplored helped us figure out which ideas were worth building on and which ones we could safelyskip.

Tatar's group published a paper describing a solar-powered debris collector concept [1]. Their calculations on panel sizing and motor power gave us a useful starting point. But here's thecatch—they never actually built anything physical. All theory, no wet feet. We appreciated the math but wanted to go further and dunk a real prototype intoreal water.

Manikanda and Rajasekaran wentthe IoTroute, adding smartphone connectivityso operators could track their robot remotely[2]. Coolfeature,nodoubt.Problemwas,theirsensorschokedwheneverwatergotmurky.Sincemostpollutedlakesprettymuchdefine murky, this seemed like a dealbreaker for practical use. We filed away the remote monitoring idea for later but focused first on making sure our collection mechanism worked regardless of water clarity.

Subhashini'steambuiltaworkingmodelthatactuallycollecteddebrisintestpools[3].Finally,somethingtangible!Unfortunately, their bin filled up super-fast, forcing constant trips back to shore for emptying. Great for demos, less great for cleaning anything bigger than a backyard pond. We made a mental note to design a bigger storage compartment.

Megalingam and colleagues simulated a tank-cleaning robot inside Gazebo software [4]. Their path-planning algorithms looked slick—neatzigzagpatternscoveringeverycorner.Butsimulationsassumestillwater,flatbottoms,andpredictableboundaries.Real lakes laugh at such assumptions. Waves slosh, winds gust, and shorelines curve in weird ways. We borrowed some of their algorithmic thinking but braced ourselves for messier reality.

Kong's research pushed into AI territory, using cameras and neural networks to identify trash [5]. Impressive tech, honestly. The downside?Expensivehardware,heavycomputation,andsoftwarecomplexitythatwouldterrifymostmunicipalmaintenancecrews. We shelved the computer vision dream for version two and stuck with simpler sensing for now.

Patternsemergedfromthisreading.Manydesignsstayedonpaper.Thosethatgotbuiltoftenstruggledwithstoragecapacity,sensor reliability, or cost. Almost nobody combined solar power, autonomous navigation, and mechanical collection in one affordable package. That gap became our target.

III. PROBLEM STATEMENT

Trash floating on thesurfacemaylook harmlessatfirst, butitsimpact becomespainfullyclear when thesurroundingwater can no longer support healthy aquatic life. Plastics block sunlight that underwater plants need for photosynthesis. Decomposing organic wastesucksoxygen outofthewater,suffocatingaquaticlife.Microplasticsworktheirwayintothefoodchain,endingupondinner plates eventually. Clogged drainage channels cause flooding during monsoons. Property values tank near polluted lakes, hurting local economies.

Current cleanup approaches suffer from hard limits. Manual labor puts workers in contact with contaminated water, risking infections and skin diseases. Hiring enough people to maintain continuous coverage blows municipal budgets. Human crews can onlywork duringdaylightandfair weather,lettinggarbagepileupovernightandduringrains. Motorizedboats burn diesel,adding pollutionwhilesupposedlyremovingit—ironic,right?Existingsolutionsrarelyscale;whatworksforatemplepondfailsmiserably forasprawlingurban lake.Wewantedtoflipthisscript.Imaginearobotthatcleansrain orshine,runsonfreesunshine,steersitself without a driver, and costs peanuts to operate once you buyit. That vision guided everychoice we made.

IV. PROPOSED SYSTEM

Ourmachinefloatsontwinhulls,cruisesusingpropellerthrust,scoopsdebrisontoaconveyorbelt,dumpsthehaulintoan onboard bin, and powerse verythingthroughrooftopsolarpanels.Threesubsystems—mechanical,electrical,andcontrol—work togetherto make this happen.

A. Mechanical Bits

Stability mattered above all else. A robot that tips over every time a wave hits becomes useless pretty quickly. Catamaran hulls solvedthisnicely.Twoparallelfloatsspacedapartcreateawidebasethatresistsrolling.Wecuthullpiecesfromthickpolyethylene sheets—the same plastic used in water storage tanks—because it handles sun, water, and knocks without corroding or cracking.

Aflatdeck bridgesthegapbetween hulls,holdingeverythingelse.Atthefrontedgesitstheconveyor assembly: arubberized mesh belt stretched between two rollers, angled downward so thelower edge dips into the water while the upper edge rises above deck level. Debris floating ahead gets scooped onto the belt and carried upward, eventually tumbling into a collection bin behind the conveyor. Drain holes let water escape while solids stay put.

Propulsion comes from two brushless motors at the stern, each spinning a small plastic propeller. Running both at equal speed pushestherobotstraightahead.Speedinguponewhileslowingtheothercausesturning.Reversingbothbackstherobotup.Simple, effective, no rudders needed.

B. Electrical Bits

Twomonocrystallinepanelssitontop,angledslightlysorainwater slidesoffandlowsunstillreachesthecells.Togethertheycrank outaround forty wattsunderbrightskies.AnMPPTchargecontrollersqueezesmaximumpowerfromwhateverlighthitsthepanels and feedsit in to a lithiumironphosphate batterypack.Wepickedthisbatterychemistrybecauseithandlesheatwell,laststhousands of charge cycles, and won't catch fire if something goes wrong—a comforting thought when electronics sit surrounded by water.

From the battery, power flows through a distribution board with fuses protecting each branch. Motors get their own high-current line; delicateelectronics geta separateregulated supplysovoltagestays rock-steadyeven when motors drawsudden bursts. Wires run through sealed conduits, connectors use waterproof plugs, and everyjunction hides inside a silicone-sealed enclosure.

C. ControlBits

An ESP32microcontroller actsasthebrain.Thislittlechippacks WiFi, Bluetooth,andenough processingmuscletohandlesensor readings and motor commands without breaking a sweat. Ultrasonic sensors mounted around the hull ping nearby objects and measurehow long echoes take toreturn, translating delayinto distance. A digital compass chip tells therobot which wayitfaces, helping maintain headings despite drift.

When we want position tracking, a GPSmodule plugsin,reporting latitude and longitude everysecond or so. For communication beyondWiFirange,aLoRaradioswapsin,reachingshorestationsseveralkilometersaway.AllcomponentstalktotheESP32over standard serial connections, keeping wiring straightforward.

Firmware stitches everything together: reading sensors, deciding where to steer, adjusting motor speeds, running the conveyor, monitoring battery voltage, and occasionally shouting status updates to whoever's listening.

V. METHODOLOGY

Building something that works in water took more sweat, more failed experiments, and more trips to the hardware store than we initially expected. Here's roughly how we attacked the problem.

A. Pinning Down Requirements

Beforecuttinganyplasticorsolderinganywires,wesatdownandlistedwhatthefinishedrobotabsolutelyhadtodo:

- Floatuprightevenwhenwavesrockitorwindshovesitsideways.
- Moveinanydirection—forward,backward,leftturn,rightturn—undereitherremotecontroloritsown decisions.
- Senseobstaclesatleastameterawayanddodgethemwithouthumanhelp.
- Grabtypicalfloatingjunk:bottles,wrappers,foamcontainers,plantdebris.
- Runatleastfourhoursonasunnydaywithoutneedingawallsocket.
- Survivesplashes,drizzle,andtheoccasionalaccidentaldunkingofnon-criticalparts.

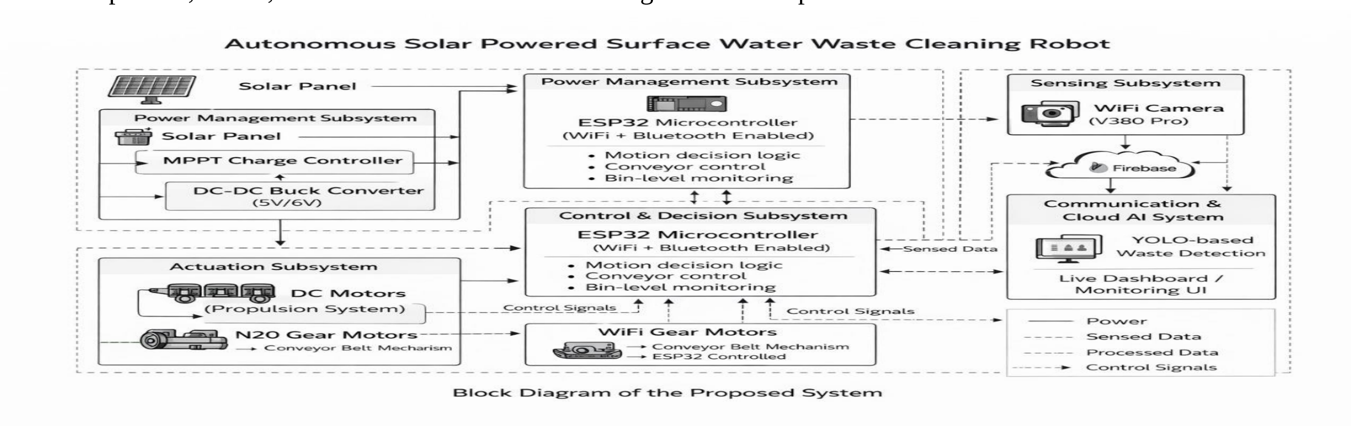

Figure1:High-levelsystemarchitectureoftheautonomouswatercleaningrobot(placeholder)

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B. SplittingUpWork

Three parallel tracks kept progress moving. One subgroup handled mechanical construction: hull fabrication, deck framing, conveyorassembly,propellermounts.Asecondsubgrouptackledelectricalwiring:solarpanels,batteries,chargecontrollers,power distribution,motordrivers.Thethirdsubgroupwrotecode:sensorlibraries,motorcontrolroutines,navigationlogic,communication handlers.

Weekly sync meetings brought everyone together to bolt parts onto the evolving prototype, test integrations, and troubleshoot mismatches. Whentheconveyor motor'spower demandsfriedan undersizedfuse, wecaughtitearlyandswappedinabeefier one before lake trials.

C. Writing Firmware

Codeliveson theESP32,written mostlyin C++ with Arduinolibrarieshandlinglow-level details. Weorganizedthecodebaseinto modules, each responsible for a distinct job:

- UltrasonicDriver:triggerspings,timesechoes,filtersoutnoisespikescausedbywaves.
- CompassDriver:readsheadingvalues,appliescalibrationoffsetstocorrectfornearbymetal parts
- MotorDriver:convertsdesiredspeedanddirectionintoPWMsignalsformotor controllers.
- ConveyorDriver:startsandstopsthebeltmotor,monitorscurrentdrawtodetectjams.
- PowerMonitor:samplesbatteryvoltage,estimatesremainingcapacity, triggerslow-powermodewhenneeded.
- Communicator:sendsstatuspacketsoverWiFiorLoRa,receivescommandsfromshore
- Navigator:Implementspatrolpatterns,handlesobstaclereactions,tracksprogressacrossthewaterbody.

Asimpleschedulercyclesthroughtasksinafixedorder, ensuringsensorsgetreadoften enoughandmotorsget updatedsmoothly. Nothing fancy, but reliable.

D. StateMachineThinking

Rather than tangling ourselvesin nested if-statements, westructuredrobot behavior asa finitestatemachine. Each staterepresents a mode:

- Boot:Power-onchecks,sensorcalibration,GPSfixacquisition.
- Idle:Sittingstill,waitingforastartcommandorscheduledpatroltime.
- Patrol:Followingacleaningpatternacrosstheassignedarea.
- Avoid:Maneuveringaroundadetectedobstaclebeforeresumingpatrol.
- Stuck:Attemptingtofreeitselfifforwardprogressstallsunexpectedly.
- Return:Headingbacktodockwhenbin fillsorbatterydrops.
- Dock:Aligningwithshorestationforemptyingandcharging.

Transitionsdependon sensor readings, timers, andoperatorcommands. For example, spottingan obstacle closer thanhalfa meter flips the state from Patrol to Avoid. Clearing the obstacle and waiting two seconds flips it back.

Channel Pruning: We analyzed filter activation magnitudes and removed channels contributing minimally to predictions. This reduced parameter count from approximately 80 million to 45 million.

Post-Training Quantization:We converted the pruned modelto TensorFlow Lite formatwith8-bit integerquantization.This reduced model size to 24.5 MB.Validation accuracydegradation from quantization was less than 0.3%.

E. ChoosingNavigationPatterns

Coveringawater bodyefficientlyrequiresmorethanjustwanderingrandomly—thoughrandomwanderingworksasafallback.We coded three patterns:

- Back-and-forth:Therobottravelsstraightacross,turnsaroundatthefaredge,shiftssidewaysabit,andheadsback.Likemowing a lawn. Great for rectangular ponds.
- Expandingspiral:Startingnearthecenter,therobottracesever-largercirclesoutward.Suitsroundoroval lakes.
- Random bounce:Pick a random heading,go until anobstacle appears,turna random angle away,repeat.Handlesirregular shapes where systematic patterns get confused.

Obstacle avoidance overrides pattern-following whenever proximity sensors yell "danger." Stop, back up, swing left or right, then resume.

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VI. SYSTEM IMPLEMENTATION

A. PuttingHardwareTogether

Assemblyhappenedinourcollegeworkshopoverseveralweekends.Majorstepsincluded:

- Markingandcuttinghullpiecesfromtwelve-millimeterpolyethylenesheetusingajigsaw.
- Heat-weldingseamswithaplasticweldinggun,thentestingfor leaksbysubmerginginabathtub.
- Boltingaluminiumanglestockintoarectangulardeckframeandscrewingitontothehulls
- Mountingconveyorrollersonbearingblocksatthefront,stretchingrubberizedmeshbeltbetweenthem.
- Attachingpropulsionmotorstosternbrackets,couplingshaftstopropellersthroughwaterproofseals.
- Wiringthebatterypack,chargecontroller,distributionboard,andmotordriversinsideasealedplasticbox.
- MountingtheESP32,GPSmodule,andLoRaradioonaseparateboardinsideanothersealedbox.
- Installingultrasonicsensorsbehindacrylicsplash shieldsatfrontandsides.
- Runningmotorcablesthroughwaterproofglands,doublecheckingeverysealwithsiliconegoop.

Thefinishedrobot weighedabout eighteenkilogramsdry, displaced enough water tofloat with comfortable freeboard,andlooked vaguely like a tiny catamaran ferry with a trash compactor strapped to its nose.

B. DevelopingSoftware

Coding happened in parallel with hardware, using a desktop simulation to test logic before deployment. We faked sensor inputs, watched how the state machine responded, and squashed bugs without risking a swim to retrieve a malfunctioning robot.

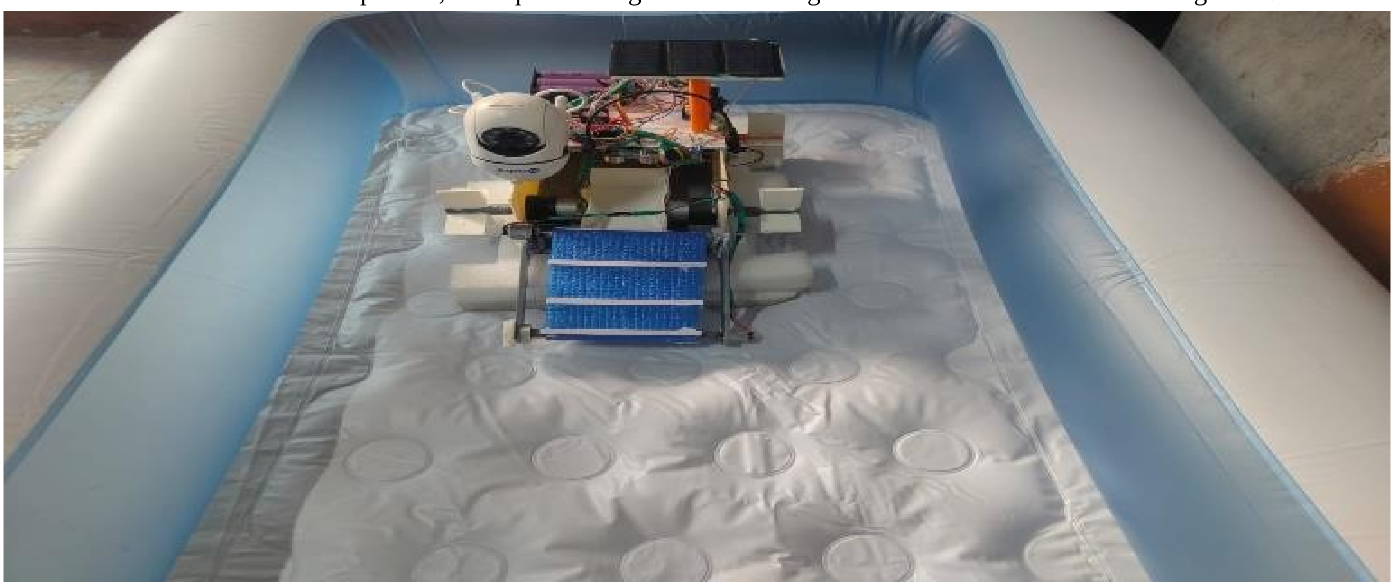

Figure2:Finishedprototype floatingduringearlytesting,conveyor beltandsolarpanelsvisible

Onceconfident,weflashed firmwareontotheESP32,powered uptheprototypeon dryland,andverifiedthatmotorsspun,sensors returned sane values, and communication links connected. Onlythen did we dare carrythe thing to water.

VII. RESULTS AND DISCUSSION

A. Stabilityin Water

Thetwin-hulllayout turnedout tobefar steadier than weimagined. Weeven pressed down on onesidejusttoseehowitbehaved, and it poppedright back intoplacewithout fuss. Even when thebreezepushed against it,theplatform stayed level enough that we never worried about it tipping.

B. HandlingandMovement

Figure shows the observed steering and movement behavior of the water robot during testing. Steering through differential thrust workedbetterthanexpected.Smoothturnswereeasy,whiletightbendsneededonemotortobackofforbrieflyreverse.

Thecontrolsoftwareresponded quickly, andalthough therobot wasn't fast—about a meter per second—itmoved ata pacethat let us actually observe what it was doing without sprinting after it.

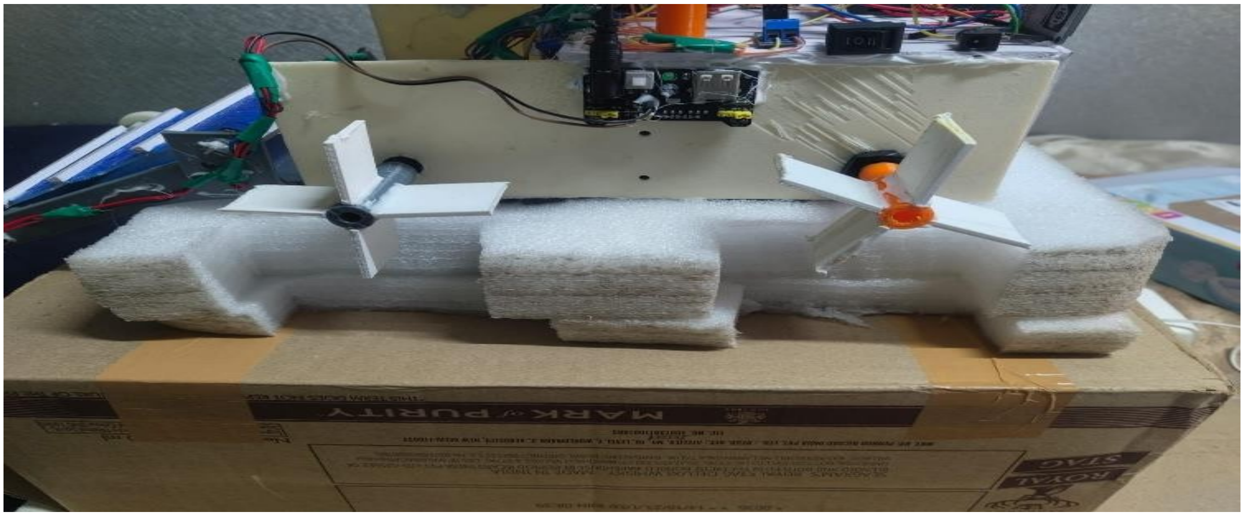

Figure3:Handlingandmovementbehaviorofthefabricatedwaterrobot

C. Handling and Movement

Duringtrials,wetossed in bottles, snack wrappers, foam cups, andeven bunches of water hyacinth.Most ofthedebrisrodeup the conveyor without trouble. Thin plastic sheets caused the most irritation since they sometimes slid underneath instead of being scooped. A soaked branch jammed therollers once, but widening the gap solved that issue for therest of theruns.

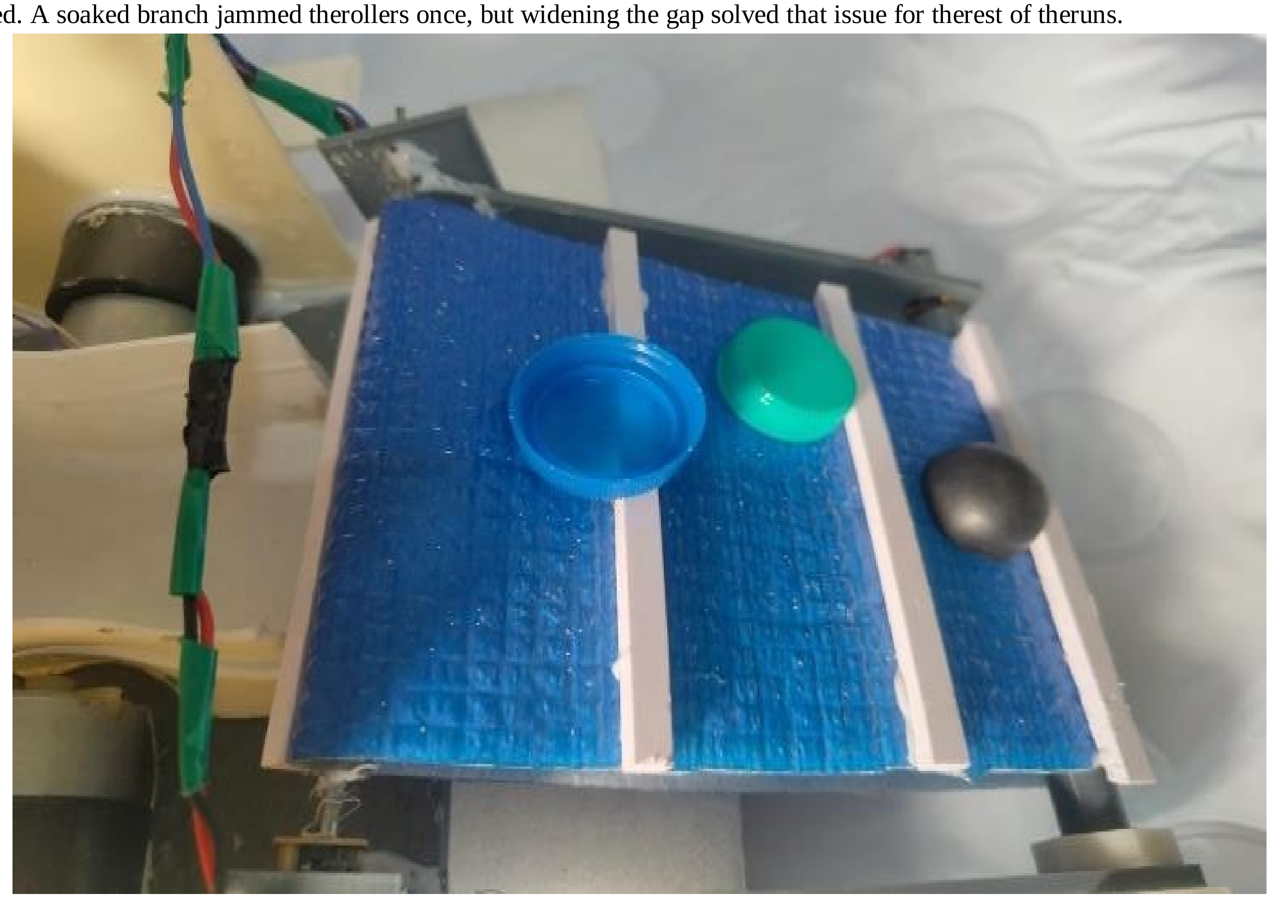

Figure4:Debriscollectionoperation ofthefabricatedwaterrobot

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D. Sensing Obstacles

In the tank and pond, the ultrasonic sensors behaved almost flawlessly—the walls gave clean echoes, making detection straightforward.Thelakewasn'tascooperative.Partiallysubmergedlogsreflectedsoundinoddways,givinginconsistentreadings. Adding side-mounted sensors helped the robot spot objects that weren't directly ahead, reducing the number of sudden evasive maneuvers.

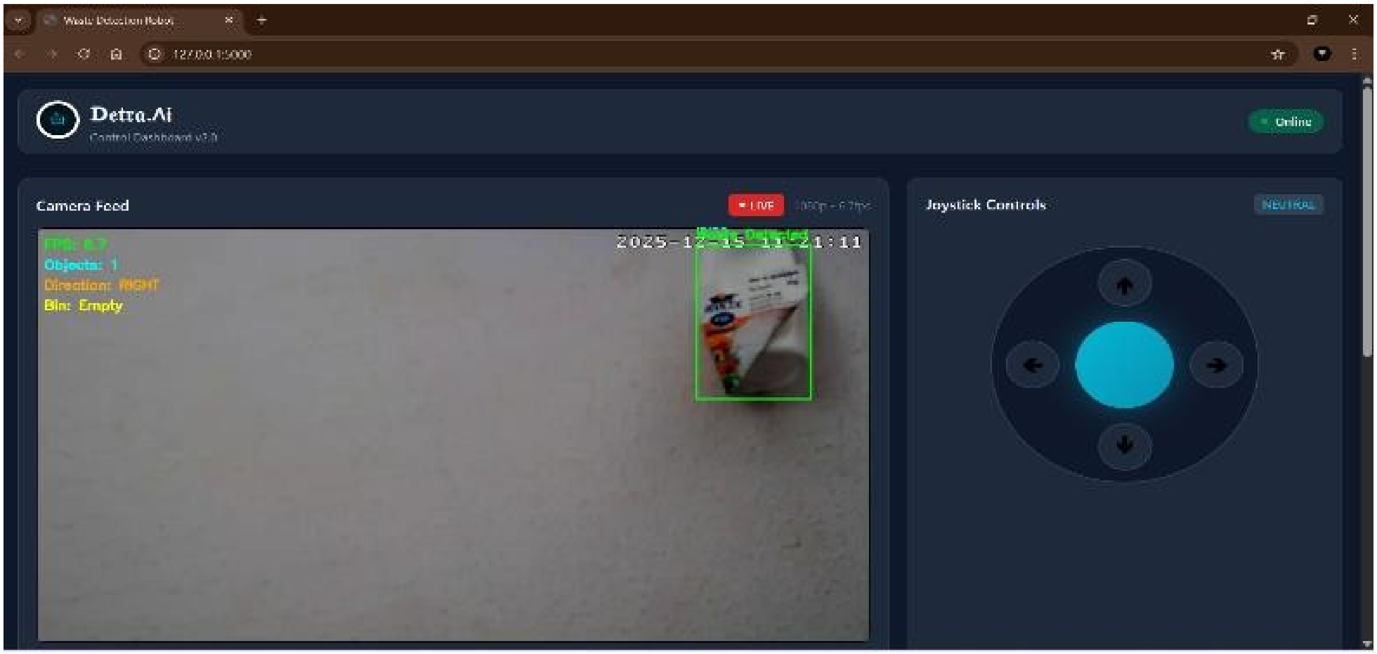

Figure5:Real-timeobstacledetectionandsensorresponseobservedduringwaterenvironmenttesting

E. Modellearningtrendsforwaterwastecategories

Thefigureshowshowthewater wasteclassificationmodellearnedover time.Accuracyimprovesgraduallywhilevalidationresults remain closetotrainingvalues,suggesting stablelearning.Atthesametime,thereductionin loss indicates thatthemodel becomes morereliableastrainingcontinues.Therecallandprecisionresultsremain fairlyconsistentacross alldatasplits,showingbalanced performance for different water waste categories.

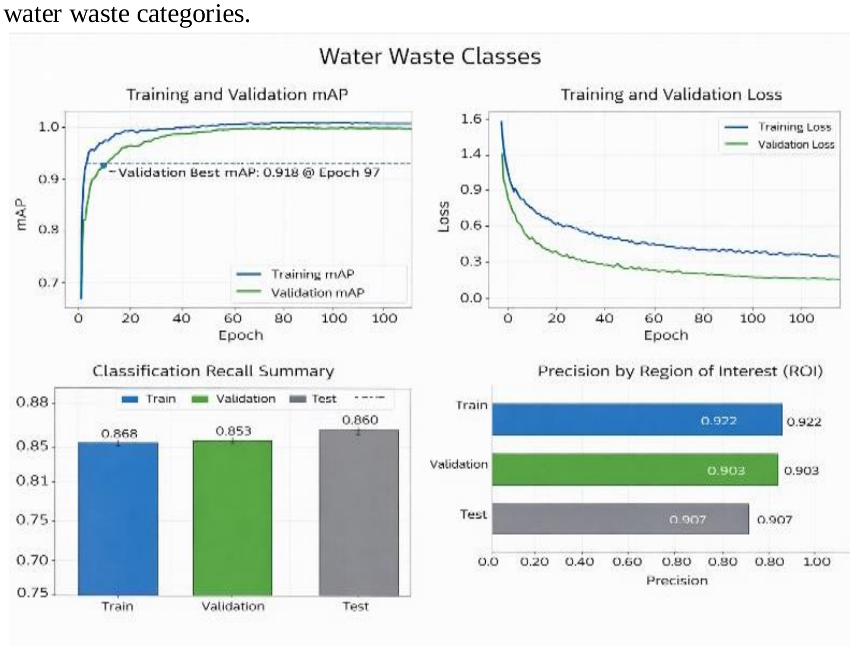

Figure6:Modeltrainingoverviewfor waterwasteclasses

F. Power Use and Runtime

Whenthesunwasstrong,thesolarpanelssuppliednearlyasmuchenergyasthesystemconsumed,andthebatterylevelstayed steadyor climbedslightly. Overcastdays wereadifferentstory;sunlightdroppeddrastically,andtherobotran forabout three hoursbeforehitting thecutoff voltage. Leavingitin thesunafterwardsfor anhour or sowasusuallyenough torechargeitfor a short follow-up run.

Figure7:Solarchargingandbatteryresponse ofthewaterrobotduringtesting

Issues That Showed Up

Afewproblemsstillremindedusthatthisisanearlyprototype.Heavywoodendebriswassimplytoomuchfortheconveyorsystem, causing thebelt toslip. Strong winds on thelakeoccasionallyshoved therobot sideways faster than themotors could compensate, whichmessed with theplannedcleaningroute.TheGPShadmomentswhereitrandomlyshifted position byseveralmeters, which madethepath log look a bit chaotic. Noneofthesesetbacks broketherobot, but theygaveus a clearer idea of whattorefinenext. Despite all the quirks and surprises, the overall results were encouraging. The robot stayed afloat reliably, moved under its own control, gathered debris, and managed to keep itself powered on sunlight for most of the testing. It wasn’t perfect—early versions never are—but it showed that the concept works in real water and not just in design sketches.

VIII. CONCLUSIONS

Whatstartedasfrustrationwithasmellylakebecamemonthsoflatenightsarguingoverhullshapes,meltingourfingersonsolderingirons,andcheeringwhentherobotfinallyscoopeditsfirstbottlewithoutsinking.Alongtheway,welearnedthatbuildingsomething real beats reading about it any day. Our robot demonstrates that autonomous, solar-powered water cleanup is achievable without exotic materials or astronomical budgets. Twin hulls keep it stable, solar panels keep it fed, conveyors keep debris moving, and simplesensorskeep itout oftrouble. Municipalbodieslookingfor affordablecleaningoptionsmight findplatformslikethisworth alook. Plentyofroughedgesremain. Heavydebrisstilldefeatstheconveyor.Currentsandwindpushharderthanourmotorsprefer. GPSwandersmorethan we’d like. Fixingtheseflaws will takeanother round ofdesign, fabrication,andtestingwork We’reeager to continue.

IX. FUTURE IMPROVEMENTS

Whatstartedasfrustrationwithasmellylakebecamemonthsoflatenightsarguingoverhullshapes,meltingourfingersonsoldering irons,andcheeringwhentherobotfinallyscoopeditsfirstbottlewithoutsinking.Alongtheway,welearnedthatbuildingsomething real beats reading about it any day. Our robot demonstrates that autonomous, solar-powered water cleanup is achievable without exotic materials or astronomical budgets. Twin hulls keep it stable, solar panels keep it fed, conveyors keep debris moving, and simplesensorskeep itout oftrouble. Municipalbodieslookingfor affordablecleaningoptionsmight findplatformslikethisworth alook.Plentyofroughedgesremain.Heavydebrisstilldefeatstheconveyor.Currentsandwindpushharderthanourmotors prefer. GPSwandersmorethan we’d like.Fixingtheseflawswilltakeanotherroundofdesign,fabrication,andtesting -workWe’reeager to continue.

- Onboardvisual cues:We’vetalkedabout addingatinycamerasotherobot can getabasicsenseofwhatitiscollecting.Nothing complicated—just enough to tell plastic apart from plants or random junk drifting around.
- Reducingsidewaysdrift:Wheneverthewaterstartedmoving,therobotlikedtowanderoff-course.AsimpleIMUorflowsensor could help it hold its line instead of sliding gently in the wrong direction.

- Lettingtherobotdockitself:Rightnow,someonehastobringitback,emptythebin,andplugitin.Asmallguidingframeon the shore, plus wireless charging, would let therobot finish a run and settle itself without assistance.
- Team-basedcleaning:Wekeepimaginingwhatwouldhappenifseveralrobotsworkedtogetherinsteadofonedoingallthelaps. With basic communication between units, theycould divide the water bodyand clean much faster.
- Testingbeyondcontrolledsites:Weeventually wantto seehow the robotbehavesinrealproblemareas.Working withlake groups or local authorities would give us feedback from people who deal with polluted water everyday.

X. ACKNOWLEDGEMENT

This project only came together because a lot of people quietly helped us along the way. Our professors at East West Institute of Technologyencouraged theidea even when it wasstill just arough sketch on paper. Thelab staff guided usthrough tool mishaps, wiringmistakes,andtheoccasionalaccidentalsplash zonewecreatedduringtesting. Our classmatespushed uswith questionsthat forcedustorethinkpartsofthedesign wethoughtweredone.Andweoweagratefulnodtothepark'ssecurityguard,whowatched us carrya strange floating machine toward the pond and, wisely, chose not to ask too manyquestions. We appreciate every bit of support we received.

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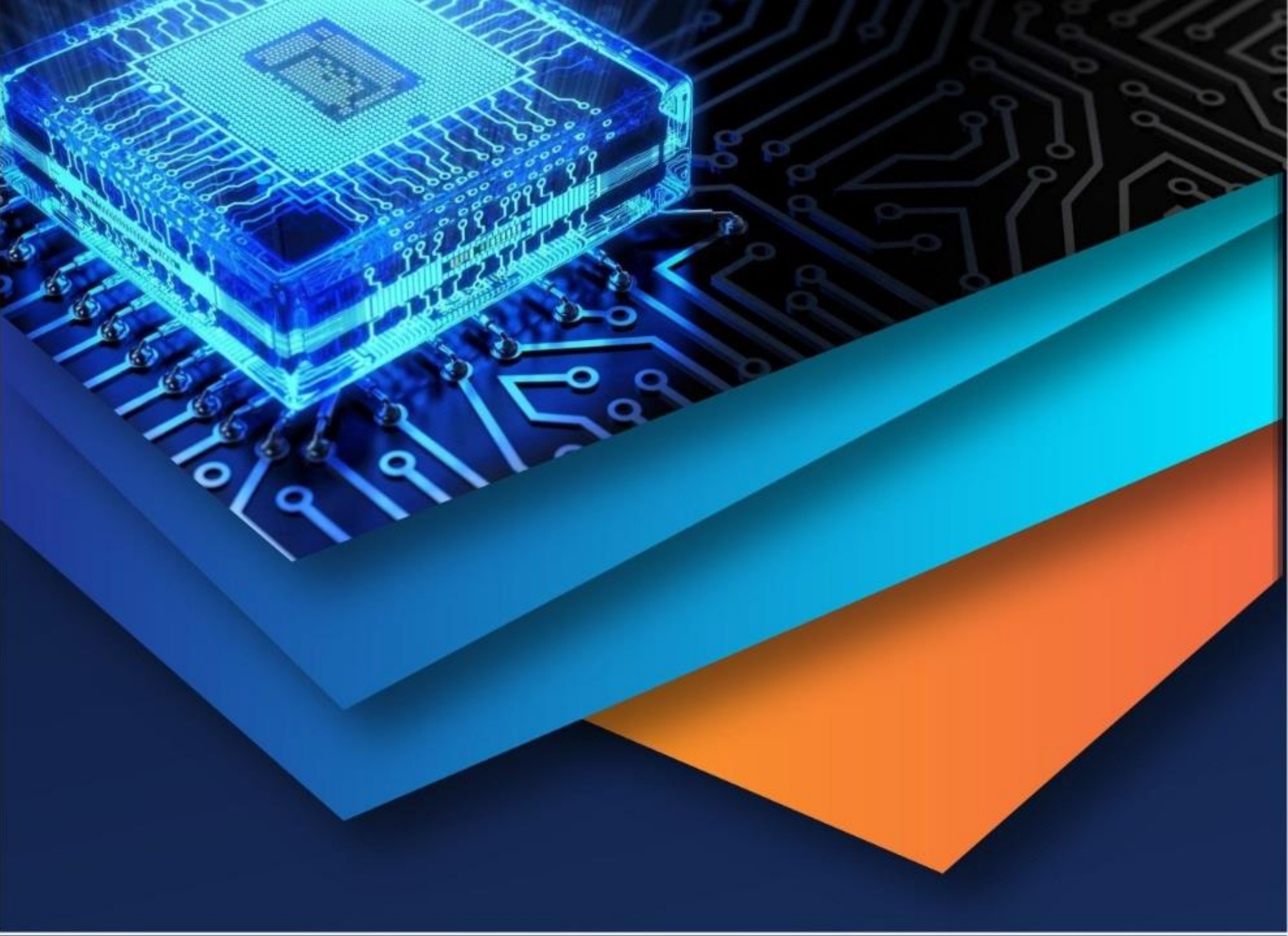

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