

Design and Pilot Evaluation of an Arduino Based Multimodal Medical Delivery Cart

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Abstract—An Arduino based delivery cart was developed to investigate the coordination of guided mobility, color recognition, and surrogate item placement for medical logistics. The modular architecture combines a microcontroller, track sensing, motor actuation, and a servo driven handling mechanism, with provision for future identity verification and remote monitoring. A pilot evaluation used a laboratory field measuring 4.08 meters by 1.75 meters, with pipe, narrow bridge, and stair obstacles connected by a black guide line. Glass beads represented delivery items, and the cart deposited them into a box matching a selected target color. Five recorded trials were analyzed descriptively. Mean total task time was 26.90 seconds with a sample standard deviation of 2.55 seconds. Mean recognition time was 3.74 seconds with a sample standard deviation of 0.83 seconds. All five trials ended with correct placement, although one bridge passage involved a stall and one stair passage required a retry. These results demonstrate the feasibility of coordinating traversal and color guided placement in a controlled surrogate task. The small sample and recovery events limit conclusions about unattended reliability. Clinical medication identification, infection reduction, and integration with hospital information systems require separate validation.

Keywords—Arduino: Color recognition: Medical logistics: Mobile robot: Multimodal sensing: Pilot evaluation.

I. INTRODUCTION

Medical logistics involves transporting supplies to the correct destination while preserving the relationship between an item and its intended recipient. Mobile robots support this workflow by combining physical transport with task scheduling and status reporting. An IoT connected hospital logistics platform demonstrated web based monitoring and control of a mobile robot [1]. This integration illustrates that delivery involves an information workflow as well as a moving platform.

A successful demonstration must be followed by evaluation of reliability in a shared clinical environment. Structured navigation benchmarks with quantitative metrics and increasing task complexity have been demonstrated on two hospital oriented mobile platforms [2]. A compact laboratory track can expose coordination problems during early development, but hospital traffic, elevator access, long operating periods, and clinical payloads require additional tests.

Correct transport also differs from correct medication administration. Poon and colleagues showed that the implementation details of barcode assisted dispensing affected medication error outcomes [3]. Consequently, color recognition is useful for demonstrating destination matching, whereas verification of a drug, patient, and prescription requires explicit identifiers. In the present experiment, color labels encode simulated destinations and glass beads serve as inert payloads.

Arduino compatible obstacle crossing and color sorting demonstrators provide an established engineering foundation. A public Robotway design combines a Basra controller, track sensing, obstacle traversal, and color dependent placement [4]. Building on this foundation, the present work examines a medical logistics task formulation, a modular integration architecture, and five surrogate delivery trials. Its contribution is an engineering integration and pilot evaluation.

The study examines completion of the combined traversal and placement task, recorded task durations, and intermediate irregularities. Identification and communication extensions are presented as future integration work.

II. SYSTEM DESIGN

A. Functional Architecture

The cart is organized into sensing, control, mobility, and handling subsystems. Track reflectance provides information for guided movement; color sensing identifies the target and candidate delivery boxes. The controller coordinates the motor drive and servo actions so that the payload can be carried across the course and released at the matching destination. Fig. 1 shows this functional organization. Solid connections represent the prototype workflow considered in the pilot evaluation; the dashed connection denotes extensions outside that evaluation.

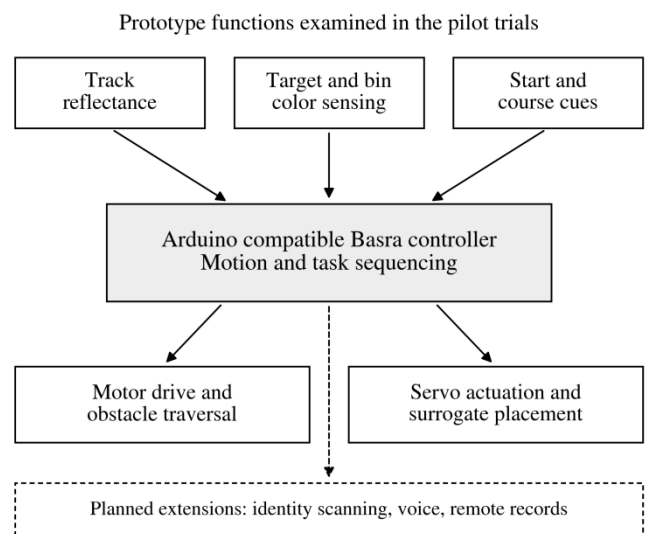


Fig. 1. Functional architecture of the cart. Dashed elements are planned extensions and were not assessed in the five trials.

The Basra board is an Arduino compatible controller built around an ATmega328 class microcontroller. It coordinates sensor acquisition and actuator sequencing. The documented UNO R3 controller class provides a 16 MHz processor, 32 kB of flash memory, and 2 kB of SRAM [5]. The expanded architecture allocates image processing, speech interpretation, and hospital network transactions to separate optional modules.

Table I summarizes the role of each subsystem and the scope of the available evaluation. In this study, multimodal refers to the use of different sensing channels for movement and destination selection. The trials examine their coordination at task level. They do not establish the performance of a probabilistic sensor fusion method.

TABLE I. SUBSYSTEMS AND EVALUATION SCOPE.

Subsystem	Role	Evaluation scope
Control	Arduino compatible Basra	Task sequencing
Track sensing	Guided motion	Course traversal
Color sensing	Target and box matching	Recorded labels and placement
Motor and servo drive	Movement and handling	Final task outcome
Identity and link	Future workflow extension	Not evaluated

B. Mobility and Handling

The mobility subsystem combines driven wheels with servo actuated auxiliary mechanisms for obstacle negotiation. Left and right motor channels support steering along the guide line. The motion software is structured around left, middle, and right reflectance inputs, PID control variables, and buffers for smoothing sensor samples. The mechanical design includes front and rear support elements and a separate handling arm. This organization allows obstacle traversal and item placement to be treated as successive operations.

The pilot study evaluates passage over the installed pipe, narrow bridge, and stair obstacles. Maximum climb angle, payload capacity, and manipulator repeatability require separate characterization. The present assessment concerns coordination of motion and placement at task level.

C. Color Recognition and Interfaces

The destination vocabulary comprises red, blue, and green. A selected target label is retained during the delivery sequence and compared with the labels associated with the receiving boxes. Reordering the boxes prevents the target color from being represented by a permanently fixed box position. The evaluated endpoint is placement in the matching box, which tests the combination of label interpretation, destination selection, and actuation.

The expanded sensor design specifies a TCS3200 option. This device has selectable photodiodes and a digital output frequency proportional to irradiance [6]; it requires filter selection and pulse or period measurement rather than a direct I2C transaction. The pilot records contain categorical labels and recognition times. Sensor waveforms and calibration data would be needed to characterize the accuracy of the specific sensing implementation.

A future identity module would associate the task with machine readable item and recipient identifiers. A voice module could provide user commands, and a communication module could transmit task states to a remote application. These are

architectural extensions. The experiment described here provides no quantitative results for barcode decoding, radio frequency identification, voice recognition, or hospital database connectivity.

III. TASK CONTROL AND EXPERIMENTAL METHOD

A. Delivery Sequence

After initialization and task start, the cart follows the guide line and traverses the installed obstacles. It obtains and retains the selected target label, identifies the corresponding box, and operates the handling mechanism to deposit the surrogate item. Completion is assessed from the recorded final placement and obstacle passage outcomes.

A trial can reach the correct destination despite an intermediate stall or retry. The analysis therefore retains traversal irregularities alongside final placement. Whether a recovery was autonomous cannot be determined when intervention status was not recorded.

B. Laboratory Field and Surrogate Task

Testing used a floor field measuring 4.08 m by 1.75 m. The course included a pipe, a narrow bridge, stairs, and colored receiving boxes linked by a black guide line. Selected obstacles had marker lines 0.20 m before and after them. The layout imposed guided traversal and localized changes in support conditions within a compact indoor setting. It was a laboratory obstacle course rather than a hospital corridor.

Glass beads carried by the cart simulated the delivery payload. The target color was selected by drawing a color card, and the order of the receiving boxes was also varied by drawing. The recorded recognized colors were red, blue, green, red, and blue. Thus, the sample contains two red labels, two blue labels, and one green label. This allocation permits a small feasibility demonstration but does not support a balanced comparison between colors.

Five complete trial records were available. Each record contains total task time, passage outcomes for the three obstacle types, recognition time, recognized color, and final placement correctness. The evaluation used inert surrogate items and did not involve medication administration or the analysis of patient records. No clinical effectiveness or infection control endpoint was measured.

C. Outcome Definitions and Analysis

The primary functional endpoint was correct final placement in the receiving box corresponding to the selected color. Obstacle outcomes were summarized separately as eventual passage and the presence of a reported irregularity. A run without a reported stall or retry was classified only as a run without a reported traversal irregularity; it was not treated as a verified measure of uninterrupted autonomy.

Total time and recognition time were analyzed at the recorded resolution of 0.1 s. The original timing record does not specify the timing instrument, exact start and stop triggers, or stage level timestamps. These measurements are therefore treated as recorded task stage durations, not as calibrated sensor response latencies. Retry or stall durations cannot be separated from the aggregate record.

Continuous outcomes are summarized by mean, sample standard deviation, median, and range. Standard deviations use the denominator n minus one. For correct final placement, an exact two sided 95 percent Clopper–Pearson interval illustrates sampling uncertainty [7]. This model assumes independent Bernoulli trials with a common success probability, an approximation for repeated tasks on one cart. Analysis is descriptive because the pilot has five trials and no comparator.

IV. RESULTS

A. Trial Outcomes

Table II presents all five records. Every trial ended with correct placement and eventual passage of the three installed obstacle types. Trial 2 involved a stall at the narrow bridge before passage. Trial 4 involved an unsuccessful stair attempt followed by successful passage on retry. Trials 1, 3, and 5 contained no reported traversal irregularity. Thus, five of five tasks reached the final placement endpoint, while only three of five had no reported stall or retry.

TABLE II. RECORDED SURROGATE DELIVERY TRIALS.

Trial	Total time (s)	Recognition time (s)	Color	Traversal observation
1	25.3	3.2	Red	No irregularity reported
2	28.1	4.1	Blue	Bridge stall; then passed
3	23.9	2.9	Green	No irregularity reported
4	30.5	5.0	Red	Stair passage after retry
5	26.7	3.5	Blue	No irregularity reported

Color denotes the recorded recognized label. All five final placements were correct, and all three obstacles were eventually passed. Recovery causes and intervention status were not recorded.

The observed correct placement proportion was 5/5. The corresponding exact 95 percent binomial interval was 47.8 percent to 100 percent under the stated model. This wide interval shows why the observed outcome cannot establish a high long term success probability. The bridge and stair observations also demonstrate that correct eventual placement can coexist with interrupted traversal.

B. Task and Recognition Times

Mean total task time was 26.90 ± 2.55 s, with a median of 26.7 s and a range of 23.9 to 30.5 s. Mean recognition time was 3.74 ± 0.83 s, with a median of 3.5 s and a range of 2.9 to 5.0 s. The values after the $\pm$ sign are sample standard deviations. The coefficients of variation were 9.48 percent for total time and 22.26 percent for recognition time.

Trial 3 had the shortest total and recognition times, whereas Trial 4 had the longest values for both measures. The two trials with traversal irregularities also had the two longest total times. This co-occurrence is descriptive: the record does not isolate recovery duration from movement, recognition, or handling time. It therefore does not establish how much either irregularity contributed to the total duration.

The greater relative variation in recognition time identifies a stage that merits more detailed instrumentation. It does not demonstrate a color specific effect, because the colors were unevenly represented and environmental conditions were not varied systematically. A separate sensor evaluation would be

needed to estimate false recognition rates or the effects of illumination and sensing distance.

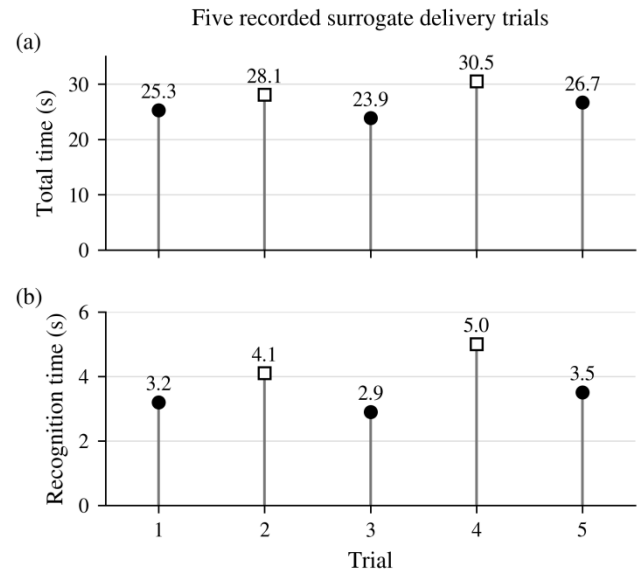


Fig. 2. Recorded times for the five trials. Filled circles indicate runs without a reported traversal irregularity; open squares indicate the bridge stall or stair retry. Each point is one trial.

V. DISCUSSION

A. Interpretation of the Pilot Evaluation

The trials demonstrate coordination of guided traversal and color dependent placement within one laboratory task. Reporting individual observations preserves the distinction between eventual completion and uninterrupted operation. The bridge stall and stair retry identify transitions requiring further examination before the cart can be assessed for unattended use.

A laboratory pipe, narrow bridge, and stair course challenges chassis support and motion sequencing, but it is not a direct representation of the usual hospital delivery route. The measured task duration cannot be converted into corridor speed because the traversed path length was not recorded. Likewise, successful passage of a particular installed obstacle does not establish maximum slope capability or general stair climbing performance.

These results provide a baseline for subsequent development. A manual delivery comparator, alternative controller, and ablation of sensing channels would be needed to quantify efficiency gains or the value of additional sensors. The present evidence establishes feasibility within the surrogate task and identifies traversal irregularities for the next iteration.

B. Transition toward Medical Logistics

Color matching models a destination choice, but several medicines may share a label color and a single destination may require several items. Clinical use would therefore require independent checking of item identity, recipient identity, and the active delivery order. The barcode dispensing study in [3] emphasizes the importance of how identifiers are checked within the workflow. No medication safety effect can be inferred from correct placement of glass beads.

The next integration stage should make task authorization and physical release separate operations. A proposed workflow would validate the item and destination identifiers before enabling release, record the release result, and retain the outcome for review. Voice commands would request an operation rather than replace identity verification. These functions require their own test cases, including mismatched identifiers, unreadable labels, duplicate commands, and interrupted communication.

Remote monitoring is a useful architectural direction, as illustrated by [1]. Connectivity requires independent evaluation of message delivery, duplicate handling, and recovery after disconnection. Network reliability, patient data security, and hospital database transactions remain outside the present pilot evaluation.

C. Limitations and Next Evaluation

The sample is small, uses one field, and includes only one green target. Obstacle dimensions, payload mass, illumination, battery state, and intervention details were not quantified in the retained trial record. The absence of synchronized video or sensor traces prevents attribution of the two irregularities to a particular mechanism, sensing error, or controller action. Timing precision is limited by the recorded procedure, and no long duration endurance result is available.

A larger study should balance the number of trials across target colors, record obstacle geometry and payload mass, and vary illumination and battery condition deliberately. Each run should include synchronized task state timestamps and an explicit intervention log. Evaluation should distinguish completion on the initial attempt, completion after autonomous recovery, completion with human assistance, and failure. Trajectory error and stopping behavior should be measured separately from final placement correctness.

Hospital oriented tests should then introduce constrained passages, stationary and moving obstacles, and realistic delivery stations. The staged benchmarking approach in [2] provides a relevant basis for increasing environmental complexity. A matched comparison with a simpler controller would help determine whether additional sensing channels improve performance. Clinical workflow and identification tests should follow after the transport and handling behavior has been characterized.

VI. CONCLUSION

An Arduino based modular cart was designed for simulated medical delivery and evaluated using five laboratory trials with inert payloads. The records demonstrate coordinated obstacle passage and color dependent placement, while also revealing a bridge stall and a stair retry. These events make recovery behavior a priority for further development. The present evidence supports a prototype feasibility conclusion. Establishing unattended reliability and clinical usefulness will require larger and better instrumented experiments, explicit item and recipient verification, and separate validation of communication and hospital workflow integration.

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