T-Mobile Robotic Handset Validation Project

Critical Design Review Supplement

Interdisciplinary Team 17.5

MEGR 4870

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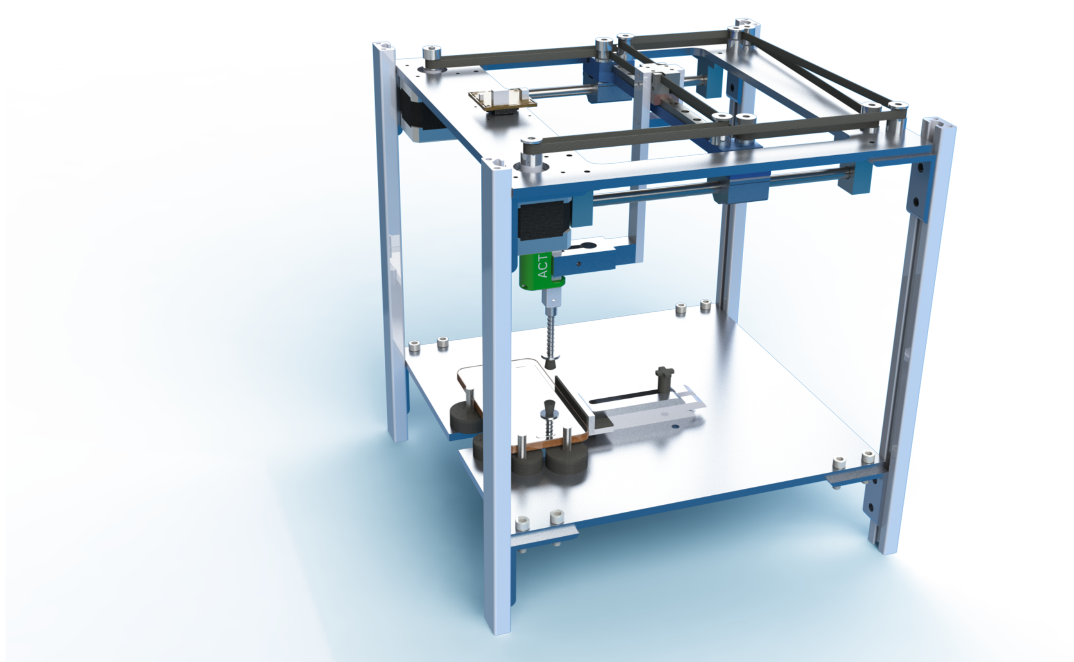
1 Proof of Concept Device

As the third largest cellular carrier in the United States, T-Mobile oversees a complex network requiring an extraordinary level of upkeep. With the continuous advent of new technologies and products, T-Mobile is finding itself validating an increasingly large volume of handsets and protocols. To this end, the company uses a number of robotic testing platforms to simulate user input on their network. These test rigs are robust, and offer a great deal of savings in time and money over human methods. However, T-Mobile's current solution is also more costly than necessary, occupies a great deal of precious laboratory space, and requires a significant amount of technician labor.

T-Mobile has approached Seattle University in the hope of securing an updated robotic validation testing device. T-Mobile has specified that the new device should represent a significant savings in cost, footprint, and labor over T-Mobile's current implementation. In addition, the company would like to expand the variety of possible test cases in order to address advanced network functions such as group-texting or video calling.

Seattle University has assigned a group of mechanical and electrical engineering students to tackle this problem, designating them Interdisciplinary Team 17.5. In analyzing the problem, and researching the technologies available today, the team has developed this proposal which defines an effective strategy for accomplishing T-Mobile's goals. The team has created a first-iteration design for a robotic handset testing device that represents huge savings in cost, footprint, and labor. The image below shows a solid model rendering of this preliminary design; a key strategy for saving laboratory space is to stack these devices thus reducing the footprint needed to test multiple handsets.

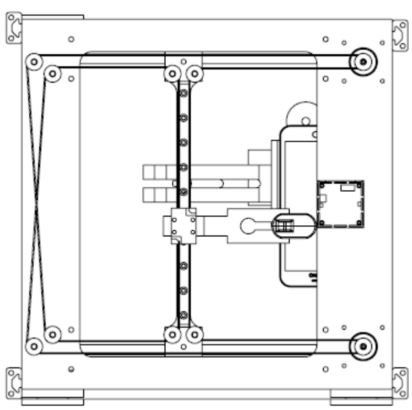


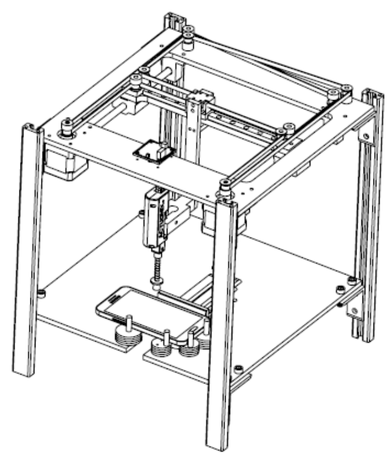
This design leverages widely available 3D printing technology and current generation imaging to achieve robotic manipulation of touchscreen devices in a manner that is both compact and inexpensive. A unique one-size-fits all mounting system with an ultra-low profile RFID configuration system eliminates time-intensive setup procedures, and allows for a great deal of flexibility. The device's modular and stack-able design opens new testing avenues, and heralds a new paradigm in handset validation. With sufficient future development, this design concept could allow T-Mobile to run any number of handset validation tests remotely, with a huge reduction in technician labor, dedicated floor space, and device costs.

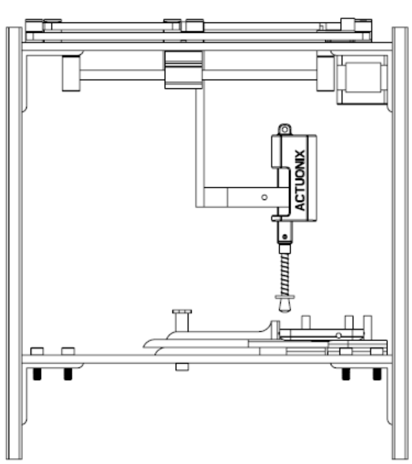
1.1 At a Glance

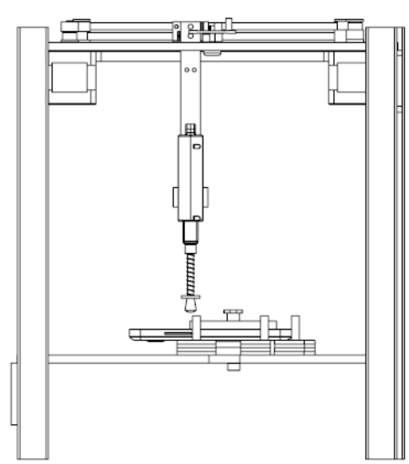
Device Specifications

Height:	35 cm
Width:	35 cm
Depth:	35 cm
Weight:	4.9 kg
Supply Voltage:	12 V
Average Power Draw:	9.88 W
Maximum Power Draw:	16 W
X-Y Translation:	2 x NEMA 17 stepper motors
Maximum X-Y Translation:	200 mm x 200 mm
Maximum X-Y Translational Speed:	300 $\frac{mm}{s}$
X-Y Accuracy:	0.2 ± 1.5 mm
Belt Life:	10 000 h (est.)
Z Translation:	Actuonix P16 Linear Actuator
Z Cycle Speed:	1 Hz
Applied Force Precision:	±7 g
Tip Elastic Constant:	0.298 $\frac{N}{mm}$







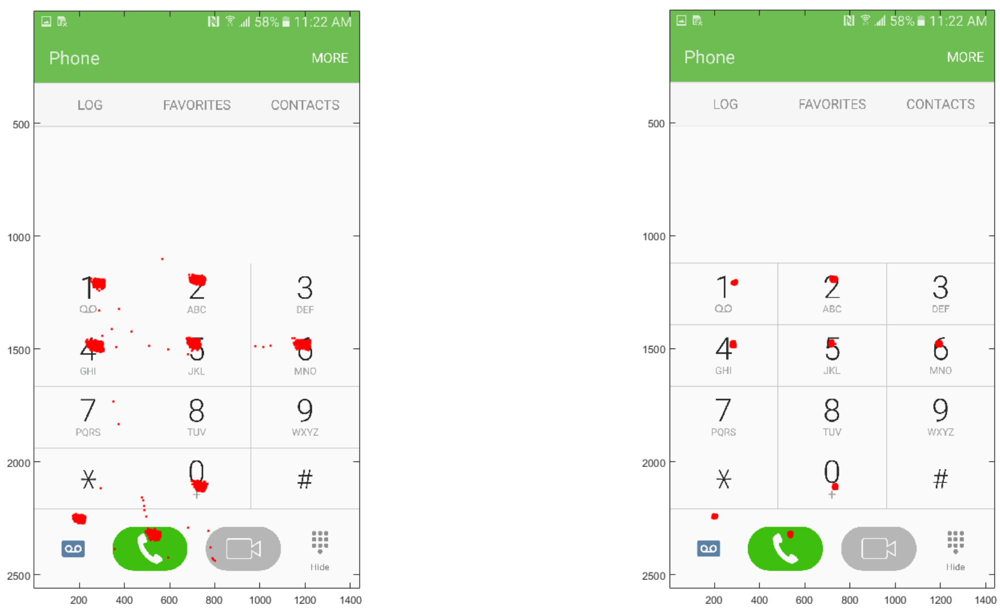


2 Proof of Concept Testing

The purpose of this section is to outline the results of testing on a single PoC device. Testing was undertaken over the course of a week of constant operation, and observations and data were gathered on critical system parameters such as accuracy, repeatability, stability, and others. A test routine was run that involved placing repeated phone calls on a Samsung j7 handset supplied by T-Mobile.

2.1 X-Y Control

Motion in the X-Y plane is critical to accurate test case execution. During the repeated test routine, touchscreen coordinates were recorded by the test handset via the Android Debug Bridge (ADB). Over 300,000 discrete events were recorded, and the results were analyzed to characterize the repeatability and accuracy of the PoC device. Figure 1a shows a schematic of the locations of all recorded data points. The system shows excellent repeatability, the spread of individual test runs is less than 1.5 mm as can be seen in Figures 1b and 2. The increased spread seen in Figure 1a is due to the testing procedure, and the limitations of the PoC device. Systematic error is introduced because each independent test session has a unique datum point in the X-Y plane. It is believed that the spread on an individual test session may be reduced with the use of box rails for both axes of motion, and the systematic datum error may be eliminated through the use of end-stops and encoded stepper motors (see section **??**).



a.) All recorded data: 316,782 discrete events, 11 test sessions. Visible outliers are due to experimental error, and are not indicative of the natural behavior of the system.

b.) Data from a single test session: 29,225 discrete events. Average grouping for a given targeted location is ±1.5 mm

Figure 1: Locations of touch events during the repeated test routine.

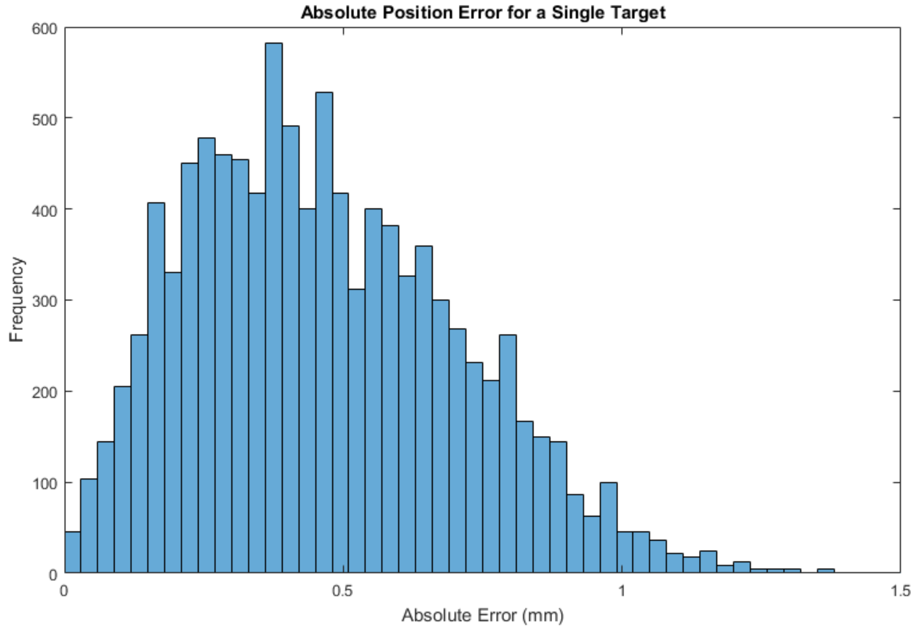


Figure 2: Absolute error of 10,127 discrete touch events targeted at the keypad 4.

2.2 Force Control

A key requirement of the validation system is the application of an accurate, repeatable force to the touchscreen of a handset. The Actuonix P16 actuator employed on this test platform provides positional feedback in the form of an ADC output from an on-board potentiometer. As seen in Figure 3, the actuation process is very consistent. The common inflection points for all actuation events shown in the figure are interpreted as the vertical position of the handset screen. It can then be stated that the distance between the inflection point, and the maximum recorded position is directly related to the maximum force applied to the handset screen. Due to the preload on the sprung tip, this force is defined as:

$$F_{Applied} = (P_{Max} - P_{Handset}) \cdot C + 250\,\mathrm{g}$$

Where $F_{Applied}$ is the force applied to the handset screen, P_{Max} is the maximum recorded position of the actuator, $P_{Handset}$ is the surface of the handset as defined by the aforementioned inflection point, and C is a conversion constant calculated using the elastic constant of the tip spring, and the conversion from Newtons to Grams. The designed preload on the tip spring is 250 g. An analysis of the force applied by the actuator for a set of 600 trials is shown in Figure 4. From these tests, it is shown that the force applied by the actuator varies by approximately 7 g with an average applied force of 377 g.

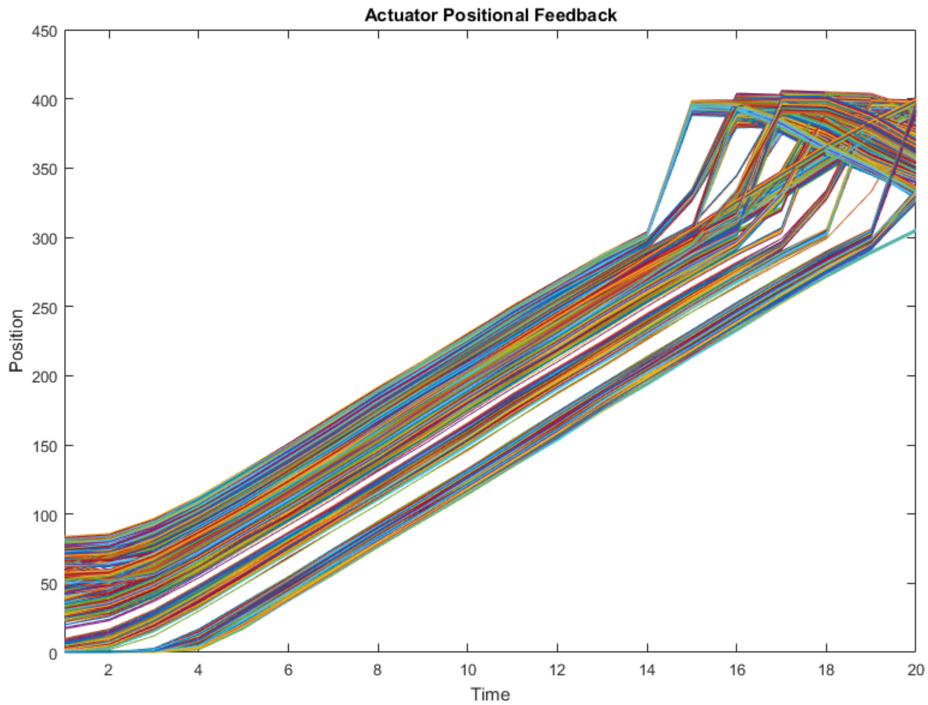


Figure 3: Positional feedback recorded from 23,263 actuation events. Note that the common inflection point for all events indicates the position of the handset screen. Position is given in the value reported by the actuator ADC, and is related to actual position by the expression $P_{actual} = \frac{P_{measured}}{1024} \cdot 50\,\text{mm}$.

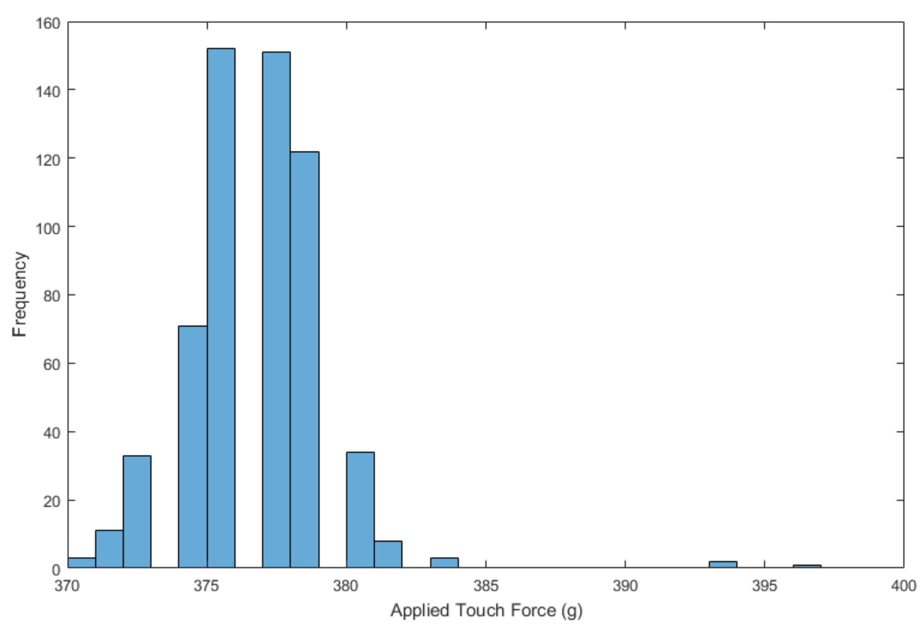


Figure 4: Histogram of applied force for 600 recorded events.

2.3 Observed Characteristics and Limitations

The following is a broad list of observations made during the test process:

- Little to no vibration of the device frame was observed. No loosening of screws or structural elements was noted.
- The rod cap of the sprung tip worked loose during testing. It was re-installed with medium thread lock and showed no further movement.
- The actuator shaft cap worked loose during testing. It was re-installed with a higher torque and showed no further movement.
- Due to a mismatch in the height of the pulleys on top of the gantry and the height of the clamp points on the carriage, the timing belt is vertically bent at the last pulley. This lead to fraying of the belt, which deposited debris on the test bed and gantry plate. No resulting change in belt tension or integrity was observed. This issue can be remedied by the use of GT2 bearings.
- Galling was observed on the sprung tip rod. Krytox lubricant was applied, and subsequent operation was smoother. The use of a precision-ground shaft and a lubrication schedule will alleviate this issue.
- No significant movement of the handset within the restraint system was observed.
- One restraint pin partially occludes the charging port at the bottom of the handset. Modification of the charging plug was necessary. This issue may be addressed by moving the pin on the PoC, and considering the use of optical layout plate (or similar) for future designs.
- Carriage and actuator mounting assembly show non-trivial deflection on extension due to yaw in the circular rail bearings. Replacing these with box rails like that used for Y translation will significantly improve positional repeatability.
- The extension speed of the actuator is currently the limiting factor in the speed of the system. The team is investigating several options to improve overall execution speed.

3 Prototype Budget

Function	Component	Price
Structure	T-Slot Extrusion	$60
	Paneling	$180
	Mounting Plates	$560
XY Motion	CNC Box Rails	$200
	Pulley w/ Bearing	$100
	High Lifecycle Belt	$100
	Servos w/ Supporting Architecture	$930
Computer Vision	High Res Network Camera	$700
Z Motivation	Air Piston w/ Supporting Architecture	$500*
	Linear Robot w/ Supporting Architecture	$3000*
	Sprung Tip Assembly	$200
Test Bed	Spring Loaded Vice	$200
	Restraint Hardware	$50
	RFID System	$80
Safety	Proximity Switch	$30
	Emergency Kill Switch	$30
Power Distribution	Fused Power Distribution Block	$75
	Power Conditioning Equipment	$20
Central Control Board	Raspberry Pi	$40
Miscellaneous	Electrical Components	$200
	Cable Management	$100
	Manufacturing Costs	$400
	Smart Glass	$500
	Lighting	$100
Unit Cost (Pneumatic)		$5,355†
Development Cost	Unit Cost x 1.40	$7,497
Unit Cost (Electromechanical)		$7,855†
Development Cost	Unit Cost x 1.40	$10,997

†This is an estimated cost for producing a single unit, higher production volumes may lower this figure.
*This is an option and is mutually exclusive. Does not include machining costs.